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The Wearing Qualities of Wool Serge : A Comparison Between the Physical Characteristics of New and Worn Materials

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Department of
Home Economics

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South Dakota State College of Agriculture and Mechanic Arts
Brookings, S. D.

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Contents

List of Figures

List of Tables

List of Tables in Appendix

The Wearing Qualities of Wool Serge

A Comparison Between the Physical Characteristics of New and Worn Materials

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Introduction

Garments made of wool fabrics are an important part of the wardrobe, especially for people who live in the northern section of the United States, where cold weather is common during a large part of the year. The protection afforded by wool clothing, the length of service rendered, and the cost involved make the selection of wool materials, or of garments made of wool fabrics, a matter of serious import. For persons living on medium or low incomes, it is especially necessary to make selections carefully to get the greatest value for the money invested.

Since wool fabrics are marketed in different weights and qualities and at different prices, a wise selection often is difficult and many questions may arise in the mind of the consumer. Will the heavier (and sometimes costlier) fabrics of a given type wear proportionately longer? Do storage and dry cleaning appreciably affect the life of a garment? Would laboratory tests of the new material, if cited by a manufacturer, give any clue as to possible wearing qualities? These and many more questions might be raised.

It is not to be expected that all such questions could be answered by any one study. However, research workers at the Agricultural Experiment Stations at the South Dakota State College and the University of Minnesota have undertaken the present investigation cooperatively in order to observe (1) the relative service to be expected from different weights of one type of worsted fabric, (2) the relation of dry cleaning and storage to service, and (3) the possible interpretation of physical test data in terms of wear.

To achieve these objectives three weights of new all wool serge, a fabric usually chosen for service rather than for style or appearance, were selected. Serge is a staple worsted fabric which is used either as a plain material in varying weights and colors, or may be modified by herringbone stripes, contrasting stripes, or small plaid effects. Since increased information concerning the interpretation of current laboratory analyses in terms of wear is needed, many investigators are supplementing laboratory data with actual wear tests. The wear test technique has been employed in the present study. Accordingly, sufficient yardage of each weight of material was purchased to provide for experimental trousers to be worn so as to show the effects of daily use and for laboratory controls on unworn cloth. These controls were lengths of cloth which provided measurements on the new materials at the beginning of the experiment, after storage, and after storage and dry cleaning for periods equivalent to the wearing periods for the trousers.

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Plan of The Experiment

FABRICS. The fabrics selected for this study were three weights of new all wool, cadet blue serge. Although the manufacturer specified the weight of these materials as 12 to 12.5, 14 to 14.5, and 16 and 16.5 ounces per linear yard, in this report they are referred to simply as 12-, 14-, and 16-ounce fabrics, respectively. All three fabrics were woven with a four-shaft, even twill construction. The warp yarns were two ply, the filling yarns single ply.

WEARING TESTS. Nine trousers were made from each of the three weights of serge. These were worn by men students at the South Dakota State College. In order to study the effect of wear and the progressive changes resulting from it, three trousers of each weight of fabric were withdrawn from service after 1500 hours, three after 3000 hours, and the last three after 4500 hours of wear.

After 300 hours of wear the trousers were returned to the laboratory, inspected, mended if necessary, and dry cleaned at a commercial establishment where standard methods were employed *(7)*[4]. After dry cleaning, each pair of trousers was checked again and returned to the student for another 300 hours of service. Trousers worn for 1500 hours were dry cleaned five times; those worn 3000 hours, 10 times; those worn 4500 hours, 15 times in all. Every student kept a reasonably accurate record of the number of hours of wear; the type of activity of the wearer; the amount of brushing, pressing, and spot removal given the trousers; and evidences of wear and damage to the garment.

The above plan, providing three trousers of each weight of fabric for each wear period, produced triplicate sets of data in every case. This provision tended to diminish the effect of any undue influence which individual wearing habits might have had upon experimental values found. Each pair of trousers originally was tailored to fit a specific student, but, as was to be expected during wartime, some of the students dropped out of school so in several cases it became necessary to refit the garment to another man. As a result, some trousers were worn for the entire period by one individual, and others by as many as five persons.

LABORATORY CONTROL SAMPLES. In the course of wear over a period of time, the fabrics in the trousers were subjected also to whatever effects aging and dry cleaning might have. Therefore, it seemed essential to include in the study some plan for measuring these variables independently of the wear factor. In order to achieve this purpose, several lengths of material were put aside as laboratory controls, one group for storage or aging and one for storage and dry cleaning. As soon as a group of trousers was ready for sampling and laboratory measurement, three lengths of the identical fabrics were removed from storage, sampled, and measured simultaneously. At the same time a second set of control samples which had been dry cleaned the same number of times as the trousers was also removed, sampled, and measured in the same manner. By means of these measurments it was planned to make some adjustments for storage and dry cleaning so that the effects of wear without these two factors could be estimated.

MEASUREMENTS OF PHYSICAL PROPERTIES. Methods of procedure, as well as the types of machines used for physical measurements, were in accordance with standards established by the American Society for Testing Materials (2), and the American Society of Textile Chemists and Colorists (1).

[4]Italic numbers in parentheses refer to Literature Cited, p. 43.

Fabric measurements. Since the major purpose of this project was to study the effects of wear, storage, and dry cleaning upon fabrics, it was necessary to have some means for measuring fabric properties which were sensitive enough to show slight changes. Visual inspection could not be depended upon since many of the changes were too small for ordinary observation; neither could it be relied upon for consistent results. Mechanical measures, therefore, were employed for the purpose of evaluating the physical properties of the fabrics and their constituent yarns and fibers, and for making pertinent comparisons.

No single measurement of a fabric, nor combination of measurements, which will serve as a standard for predicting serviceability is known. Since it was neither possible nor expedient to employ many different measurements on the trousers, only those properties were selected for measurement which were expected to yield the most useful information concerning the effects of wear. These properties included weight per square yard, thickness, number of yarns per inch, breaking strength and elongation, bursting strength and elongation, and yarn strength and elongation.

To provide a basis for fabric comparisons, all of the properties measured for the trousers also were measured for the new fabrics at the beginning of the experiment. In addition shrinkage and tearing strength were measured. These same measurements were made subsequently on the stored and dry cleaned fabrics. Colorfastness was determined for the new materials only.

The breaking strength of the fabrics was determined with a power driven tester of the pendulum type, the lower or pulling jaw of which traveled at a downward rate of 12 inches per minute. The raveled strip method was used. Bursting strength measurements were obtained by using the ball-burst attachment with the pendulum type tester. The specimen was held securely in a ring clamp and pressed against a polished steel ball, one inch in diameter, until the fabric was ruptured.

In order to evaluate the effect of light on the strength of the three fabrics, small swatches of the new materials were exposed to light from a flaming violet carbon arc enclosed in a special glass globe. The exposure periods chosen were 40, 80, 120, 200, 320, 480, and 680 hours, each interval being a multiple of forty. Six warpwise breaking strength samples were cut from each fabric and placed in the metal holders of the lamp cabinet so that a section of each sample 1⅝ inches long and the entire width of the strip was subjected to the light from the arc for periods specified. After the exposure period the exposed portions of the strip were placed midway between the two jaws of the breaking-strength machine and the residual strength determined.

Yarn measurements. Since the quality of a fabric is determined in part by the properties of the yarns from which it is made, it appeared necessary to investigate the character of the yarns taken from these three materials as well as that of the fabric. The measurements used included yarn number (worsted count—the number of 560-yard hanks per pound), twist, strength, and elongation. Ten determinations were made in each case, except for strength and elongation values, for which 50 determinations were made. These measurements were made on yarns from all fabrics except those in the worn garments, for which only the yarn strength and elongation were determined.

Yarn strength was measured on a single-strand, pendulum type, motor-driven tester. The jaws were set 10 inches apart and the lower jaw traveled downward at a rate of 12 inches per minute.

Fiber measurements. Again, since yarns are made of fibers, and since the final product is influenced by the materials of which it is composed, it was thought appropriate that the character of the fibers themselves be determined. For this purpose samples of fiber were taken at random from warp and filling yarns of each new fabric, and the length, diameter, and contour index of 500 fibers in each case were recorded. Fiber length was determined according to A.S.T.M. Designation D 519-40 *(2)* which describes the use of the wool fiber stapling apparatus.

For diameter and contour measurements, cross sections were made with the Hardy cross-sectioning device *(4)*, were mounted in euparal, and the fiber images reflected on a ground glass screen at 500 diameters magnification so that 0.5 mm. on the screen equaled 1.0 micron. The ratio of the major to the minor axis often is used to indicate the ellipticity of the fiber in cross section. Therefore, two diameter measurements, representing the major and minor axes of the fiber at right angles to one another, were taken for each fiber. Dividing the major axis diameter by the minor shows the variation in cross section and the resulting value has been recorded as the contour index. No attempt was made to evaluate the effects of wear, aging, or cleaning on the fibers.

Sampling. Ten samples were used for all fabric measurements except weight, colorfastness, effect of light on strength, and shrinkage. Four weight determinations were made for each fabric, and six samples were used for each strength value after exposure to light. Shrinkage was determined by measuring an 18-inch square at three different places in both directions of the fabric.

Yarn measurements include 10 samples each for yarn number and twist, whereas 50 determinations were used for yarn strength and elongation values. Data for fiber diameter and contour are the results of 500 measurements. Fiber length was determined by weight after sorting, and an approximately 0.5 gram sample was used in each instance.

When the trousers were ready for sampling every effort was made to locate the samples in approximately the same position on each garment regardless of size. No samples were taken near the seams. In order to show variation in wear in different parts of the garment, and also to obtain a value for strength which would be as nearly as possible typical of the whole trousers, a plan for sampling was devised by which breaking strength samples were taken from the pocket, the seat, and the knee areas. These have been referred to in this study as the top, middle, and bottom areas, respectively. The location of these areas was determined from the result of a preliminary study of the relative fabric strength throughout a pair of trousers which had been given enough wear to justify discarding. A summary of 109 breaks on this garment had indicated that the regions mentioned above represent the principal points of wear.

Samples were scattered so as to give as nearly representative a sampling as possible. No measurements were made nearer the selvedge than one-tenth the width of the fabrics (2), and in no case did samples for any one set of measurements include repetition of the same warp or filling yarns.

Conditioning. All fabric and yarn properties were measured in the textiles laboratory at the University of Minnesota, in which a standard atmospheric condition *(1,2)* of 70 degrees F. ±2 degrees, and 65 percent relative humidity ±2 per cent, is maintained. The samples were entered from a drier atmosphere, and exposed to standard conditions until moisture equilibrium was reached before any measurements were made.

Findings of The Experiment

In the following discussion many of the findings are summarized in tables and graphs. To facilitate comparisons, tables used in the discussion show only differences between means. Means for sections of trousers for each of the wear periods can be found in the Appendix. Where considerable variability was found, the analysis of variance was used to determine what proportion of the total variability could be assigned to the contributing factors. This is shown by mean square values combined with an appropriate test for significance. Since the five percent level (at which point the odds are 19 to 1 that any observed difference is not due to chance) has been accepted generally as an arbitrary division between significance and non-significance, differences reaching this level have been termed significant, and those which attain the one percent level (odds in this instance being 99 to 1 that any observed difference is not due to chance) are referred to as highly significant. Only differences found to be statistically significant have been emphasized.

Character of the New Fabrics Before Wear

Properties of the new fabrics. To a casual observer the three wool serges might have seemed very much alike, but close scrutiny disclosed that the 12-ounce fabric was lighter than the other two, felt thinner, and appeared to be made of finer yarns. This was to be expected, and was verified by laboratory measurements, which are summarized in Table 1.

Table 1. Values for Fabric Properties of Three Weights of New All Wool Serge.

Property measured	Unit of measure	12-ounce Warp	12-ounce Filling	14-ounce Warp	14-ounce Filling	16-ounce Warp	16-ounce Filling
Weight per sq. yd.	ounces	7.77		8.72		9.94	
Thickness	1/1000 in.	24.00		27.20		30.05	
Yarn Count	no. per in.	66.30	56.00	56.70	54.80	57.90	55.20
Breaking strength	pounds	49.25	43.15	57.75	55.05	65.80	59.60
Bursting strength	pounds	106.50		130.60		140.80	
Tearing strength	pounds	5.60	5.30	8.20	7.35	8.30	7.65
Elongation—breaking test	percent	29.34	27.33	32.67	35.33	34.33	34.67
Elongation—bursting test	percent	18.57		28.57		22.85	
Shrinkage	percent	6.22	1.38	5.56	0.67	5.56	1.17

Weight per square yard. The fabric weights specified by the manufacturer represent weight in ounces per linear yard. Since the 12-, 14-, and 16-ounce fabrics used in this experiment were approximately 58 inches in width, corresponding weights per square yard, in round numbers, are 8, 9, and 10 ounces, respectively.

Thickness. The thickness of the materials was determined with a compressometer, measuring in thousandths of an inch. These values, found to be 24, 27, and 30 thousandths, exhibit, as do weight measurements, a progressive increase from the 12-ounce up to the 16-ounce material. These increases represent highly significant differences in each case (Appendix Table II).

Yarn count. Since yarn count, or the number of yarns per inch, is somewhat descriptive when considering fabric properties, yarns were counted in both directions of the cloth. Warpwise the 14- and 16-ounce fabrics were approximately the same, having a count of 57 and 58, while the 12-ounce material had 66 warps per inch, a difference which confirms the earlier visual observation. Fillingwise there was little variation, since the number of yarns per inch was 56, 55, and 55, for the 12-, 14-, and 16-ounce materials, respectively. In all cases the fillingwise count was lower than the warpwise count for the same fabric. Increases in weight and thickness observed when comparing the three pieces of serge apparently have no relation to the number of yarns per inch.

Breaking strength. The strength of a fabric has been accorded major interest when serviceability is concerned, and tensile or breaking strength has been one of the measures most widely used in the textile field. Table 1 includes the results of breaking strength measurements on these materials. Warpwise breaking strength values are approximately 49, 58, and 66 pounds for the 12-, 14-, and 16-ounce fabrics, respectively, and exhibit, as do weight values, an approximately equal increase in strength among the three fabrics. (See Fig. 2, p. 17.) However, this regularity is not shown in the fillingwise direction since the 14-ounce fabric, which broke at 55 pounds, is 12 pounds stronger than the 12-ounce fabric, but only five pounds weaker than the 16-ounce material. All of these differences are found to be significant (Appendix Table II).

Bursting strength. Bursting strengths for the new materials are 106, 131, and 141 pounds for the 12-, 14-, and 16-ounce fabrics, respectively. Here again the greatest difference appears between the 12- and 14-ounce fabrics, but these differences are highly significant in all cases (Appendix Table II).

Tearing strength. The ability of a piece of cloth to withstand a tearing force is an important quality, especially when serviceability is a prime factor. Tearing strength was measured in terms of the number of pounds needed to tear the fabric. The force required to tear these three materials was essentially the same in both warpwise and fillingwise directions, a relationship which holds for all three weights of fabric. The 14- and 16-ounce serges tore at approximately eight pounds, whereas the 12-ounce material tore when subjected to a force of five to six pounds. So far as tearing strength is concerned, the 12-ounce fabric was found to be significantly weaker than the other two materials (Appendix Table II).

Fabric elongation. Fabric elongation under stress unquestionably is an important factor in garments which are subjected to stretching and strain. Elongation was measured at the same time as breaking and bursting strength. Although warpwise breaking strength, like weight, exhibits an approximately equal increase among the three fabrics, this same tendency is not apparent for elongation.

When comparing the elongation associated with breaking strength for the 12- and 14-ounce and for the 14- and 16-ounce fabrics, the only significant difference noted is between the 12- and 14-ounce fabrics in the fillingwise direction (Appendix Table II). Elongation of the 14-ounce fabric amounts to 35 per cent as against 27 per cent for the 12-ounce material.

Measurement of the elongation resulting from the application of bursting forces produced results similar to those found for breaking forces, since the only significant difference again is that between the 12- and 14-ounce materials. In this instance the elongation found was 29 per cent for the 14-ounce fabric and 19 per cent for the 12-ounce, a difference which is significant at the one per cent level.

Shrinkage from sponging. One of the major difficulties usually encountered in wool garments has been the problem of shrinkage due to repeated steaming and pressing, or to wetting. The amount of shrinkage these fabrics sustained when subjected to moisture and pressure approximated six per cent warpwise and one per cent fillingwise for all three materials. These values indicate that shrinkage was considerably greater warpwise than fillingwise, but relatively the same for all three weights of materials.

PROPERTIES OF THE YARNS. Data for yarn measurements are summarized in Table 2 and the significance of differences used in comparisons is indicated in Appendix Table II.

Yarn number. The yarn numbers (worsted count) found for the warps are approximately 19, 14, and 12, and for the fillings 16, 13, and 12, for the 12-, 14-, and 16-ounce fabrics respectively. These numbers indicate that the 12-ounce fabric was made up of somewhat finer yarns than the 14- and 16-ounce materials, and that the yarns in the two heaviest fabrics were more nearly alike. These variations in yarn number do not follow the trend exhibited by weight per square yard, where the differences between the fabric weights are approximately equal. The yarn numbers show a difference between the 12- and 14-ounce fabrics which is more than twice as great as the difference between the 14- and 16-ounce materials. The greater thickness which has been noted for each increase in weight, therefore, apparently resulted at least partially from the size of yarns used, since the thinnest fabric was woven from the finest yarns. This pattern is consistent with the yarn count, since the 12-ounce fabric which was made from the finest yarns has the highest count, a relationship which is borne out further by the coarser yarns in the heavier fabrics which have lower yarn counts.

Yarn twist. The number of twists per inch indicates that the light weight fabric was woven with yarns which are more tightly twisted than those in the heavier materials. Yarns from the 12-, 14-, and 16-ounce fabrics have approximately 9, 7, and 6 twists per inch warpwise and 10, 9, and 9 fillingwise, respectively. Thus it will be noted that the filling yarns of all the materials are more tightly twisted than the corresponding warp yarns. These differences in yarn twist, between the fabrics and within each fabric, are found to be highly significant (Appendix Table II). Again the comparable differences between the 14- and 16-ounce fabrics are much smaller than those between the 12- and 14-ounce materials. Comparing twist and thickness data, the thinnest fabric was made of yarns having the greatest number of twists per inch.

Yarn strength. The strength of the yarns increased significantly with each increase in weight of the fabrics, the greatest increment occurring between the 12-

and 14-ounce fabrics (Appendix Table II). This was true of fillings as well as of warps. In each case the warp yarns are stronger than the filling yarns for the same material. Thus the strongest warp yarns are found in the heaviest weight fabric, and they are coarser and less tightly twisted than are those in the other two weights of materials.

Table 2. Values for Properties of Yarns from the Three Weights of New All Wool Serge

Property measured	Unit of measure	12-ounce Warp	12-ounce Filling	14-ounce Warp	14-ounce Filling	16-ounce Warp	16-ounce Filling
Number	worsted count	18.58	15.76	14.40	12.83	12.36	12.25
Twists	number per in.	8.84	10.16	7.36	9.14	6.35	8.53
Strength	grams	268.2	241.2	369.4	317.2	443.0	344.8
Elongation	percent	11.02	8.02	12.72	8.88	12.36	7.60

Yarn elongation. Yarn elongation showed little variation among the three fabrics. Warpwise values range from approximately 11 to 13 percent, and fillingwise values from eight to nine per cent. Since all but one of these differences were not statistically significant, it is thought they probably are due to errors of random sampling. Comparing elongation of the warp yarns with that of the corresponding filling yarns, no significant difference is found between the warps and fillings of the 12-ounce material whereas such differences within the 14-ounce and 16-ounce materials reach the five per cent level of significance.

PROPERTIES OF THE FIBER. Since the materials and yarns were found to vary in weight, thickness, and other physical properties, it appeared logical to expect that differences might be found in the fibers from which they were made. Accordingly the length, diameter, and contour of the fibers were measured. These data are recorded in Table 3 and the significance of differences between means is shown in Appendix Table II.

Fiber length. The mean length of the fibers, both from the warp and from the filling yarns, is approximately the same, i.e., about two inches, for all three weights of fabric.

Mean diameter. The mean diameter of the fibers from the warp yarns is approximately 27 microns for both the 14- and 16-ounce fabrics, and only 24 microns for the 12-ounce material. This 3-micron difference proves to be highly significant (Appendix Table II). Mean diameters of fibers from the filling yarns, 24, 27, and 29 microns for the 12-, 14-, and 16-ounce fabrics, respectively, represent significant differences in each instance. Mean diameters of fibers from the warp yarns are approximately the same as the diameters of fibers from the fillings in both the 12- and 14-ounce materials, but differ significantly in the 16-ounce fabric. The progressive increase which has been observed in weight per square yard and thickness for all three weights of material is not found in mean fiber diameter measurements. The mean diameter of the fiber used in the 14-ounce fabric is larger than that in the 12-ounce, but fiber from the 16-ounce material shows no increase over the 14-ounce material.

Contour index. No variation in contour was found among the fibers from the three fabrics since the contour index, which ranges from 1.23 to 1.26, shows approximately the same amount of ovality in all fibers. Thus it appears that these serges were all made of fibers which have about the same amount of ellipticity and the same length, and therefore possess spinning qualities which are essentially the same in every case.

Table 3. Dimensional Measurements of Wool Fibers from the Three Weights of New All Wool Serge

Fiber measurement	Unit of measure	12-ounce Warp	12-ounce Filling	14-ounce Warp	14-ounce Filling	16-ounce Warp	16-ounce Filling
Fiber length	inches	1.88	1.95	2.21	2.36	1.86	2.42
Mean diameter	microns	24.45	24.34	27.04	26.60	27.03	28.56
Contour index		1.24	1.24	1.23	1.24	1.25	1.26

Character of the Fabrics After Wear

Mean values for the measurements made on the worn garments are assembled in Appendix Table I. Each value is a mean for the three replicate garments. The differences between the values for the new and the worn fabrics are given in Table 4, and shown graphically in Figures 1, 2 and 3.

Although these values portray the effects of use, or wear as it may be called, variations which might be due to dry cleaning or aging, to exposure to light or other conditions, also are included. However, the total effects of wear and maintenance will be evaluated first and any adjustments for dry cleaning and storage which it may be possible to make will be considered after the effects of total wear have been discussed.

The trousers were worn for 1500, 3000 and 4500 hours. For the sake of brevity, they will be referred to as wear periods I, II, and III, respectively.

Fabric properties as affected by actual wear. *Weight per square yard.* The weight of the fabrics at the end of the first period was slightly higher than that of the new materials (see Table 4). As the garments continued to be worn, however, a gradual loss in weight became evident for the 12- and 14-ounce fabrics after every period of wear. Weight of the 12-ounce material decreased between wear periods I and III from 8.21 to 7.05 ounces per square yard. The 14-ounce material decreased from 9.25 to 8.28 ounces. The 16-ounce material showed no loss in weight until the end of the third period when it dropped from 10.50 to 9.18 ounces. The 12- and 16-ounce materials, therefore, had lost approximately three quarters of an ounce by the end of the third wear period when compared with the new material, the 14-ounce fabric nearly one-half ounce.

Thickness. When the materials were subjected to conditions of actual wear it appears from data in Table 4 that the fabrics decreased in thickness with continued use. Thickness of the 12-ounce material dropped from 24.0 thousandths of an inch for the new material to 21.6 thousandths after three periods of wear; the 14-ounce dropped from 27.2 to 24.4; and the 16-ounce from 30.0 to 25.5 thousandths. Total losses, therefore, were approximately 2, 3, and 5 thousandths of an inch for the 12-, 14-, and 16-ounce fabrics, respectively. This downward trend is consistent in all but one case, although some differences are small (see Figure 1). Comparisons among the three fabrics show that after the third period of wear the 14- and 16-ounce materials were as thick, or thicker than the 12-ounce fabric when new.

Table 4. Differences Between the Physical Measurements of Three Weights of Wool Serge, Comparing the New Fabrics and Those from the Worn Trousers[1]

Fabric property	Unit of measure	12-ounce serge Wear period I	12-ounce serge Wear period II	12-ounce serge Wear period III	14-ounce serge Wear period I	14-ounce serge Wear period II	14-ounce serge Wear period III	16-ounce serge Wear period I	16-ounce serge Wear period II	16-ounce serge Wear period III
Weight per sq. yd.	ounces									
New		+0.44	—0.29	—0.72	+0.53	—0.32	—0.44	+0.56	0.00	—0.76
Wear period I			—0.73	—1.16		—0.85	—0.97		—0.56	—1.32
Wear period II				—0.43			—0.12			—0.76
Thickness	1/1000 in.									
New		+0.63	—0.90	—2.42	—0.57	—2.00	—2.83	—1.55	—2.80	—4.55
Wear period I			—1.53	—3.05		—1.43	—2.26		—1.25	—3.00
Wear period II				—1.52			—0.83			—1.75
Yarn count	number per in.									
Warpwise										
New		+0.10	+0.80	+1.10	+0.40	+0.90	+0.40	—0.60	—0.50	—0.50
Wear period I			+0.70	+1.00		+0.50	0.00		+0.10	+0.10
Wear period II				+0.30			—0.50			0.00
Fillingwise										
New		+2.80	+3.40	+3.00	+0.90	+2.30	+1.50	+0.30	+1.00	+1.00
Wear period I			+0.60	+0.20		+1.40	+0.60		+0.70	+0.70
Wear period II				—0.40			+0.80			0.00
Breaking strength	pounds									
Warpwise										
New		—2.93	—9.99	—15.06	—4.36	—9.70	—17.62	—3.43	—4.25	—22.53
Wear period I			—7.06	—12.13		—5.34	—13.26		—0.82	—19.10
Wear period II				—5.07			—7.92			—18.28
Fillingwise										
New		+0.54	—8.34	—14.34	+1.95	—6.29	—19.04	+0.48	—3.28	—22.12
Wear period I			—8.88	—14.88		—8.24	—20.99		—3.76	—22.60
Wear period II				—6.00			—12.75			—18.84

[1]The plus sign indicates a gain and the minus sign a loss when comparisons are made with values for new materials or for preceding periods.

Table 4. (Continued) Differences Between the Physical Measurements of Three Weights of Wool Serge, Comparing the New Fabrics and Those from the Worn Trousers

Bursting strength	pounds									
New		—4.97	—19.02	—31.60	—4.53	—22.85	—32.20	—0.42	—14.53	—41.15
Wear period I			—14.05	—26.63		—18.32	—27.67		—14.11	—40.73
Wear period II				—12.58			—9.35			—26.62
Elongation, breaking test	percent									
Warpwise										
New		—2.78	—2.08	—6.93	—3.08	—5.00	—7.74	—3.70	—4.37	—10.77
Wear period I			+0.70	—4.15		—1.92	—4.66		—0.67	—7.07
Wear period II				—4.85			—2.74			—6.40
Fillingwise										
New		—4.92	—6.74	—10.92	—9.85	—14.07	—17.40	—7.67	—10.63	—15.56
Wear period I			—1.82	—6.00		—4.22	—7.55		—2.96	—7.87
Wear period II				—4.18			—3.33			—4.93
Elongation, bursting test	percent									
New		—4.28	—1.24	—3.52	—10.95	—8.95	—10.29	—6.66	—5.14	—7.42
Wear period I			+3.04	+0.76		+2.00	+0.66		+1.52	—0.76
Wear period II				—2.28			+1.34			—2.28

[1]The plus sign indicates a gain and the minus sign a loss when comparisons are made with values for new materials or for preceding periods.

The statistical significance of these differences has been determined by an anlysis of variance *(3,5)*. The mean squares for these analyses, with their significance according to the "F" test, are given in Table 5 *(3,5)*.

Thickness values for the trouser fabrics after wear appear to be typical for each fabric since the mean square for replication was not significant. Grouping the three weights together, the mean square for fabrics indicates that thickness varied significantly among these three fabrics. The thickness of the three weights of serge is shown to vary also throughout the three wear periods by a highly significant mean square for periods.

Yarn count. Comparing the worn fabrics with the new, the number of yarns per inch appeared to have increased slightly after the three periods of wear for all three weights of fabric, except in the warpwise directions of the 16-ounce, with the greatest increases occurring in the 12-ounce material. This tendency was most apparent in the fillingwise direction where increases over values for the new materials varied from 0.3 to 3.4 yarns per inch. The greatest increase noted in the warpwise direction was 1.1 yarn per inch (Table 4). These increases in yarn count may be due to shrinkage.

Table 5. Mean Squares from the Analyses of Variance of Values for Certain Properties of Three Weights of Wool Serge after Three Periods of Wear, and Their Significance as Shown by "F" Tests.

Source of variation	Direction of test	Degrees of freedom	Thickness	Yarn count	Breaking strength	Bursting strength	Elongation Breaking test	Elongation Bursting test
Replications	Warpwise	2	0.12	0.02	22.64	74.51	4.69	2.13
	Fillingwise			0.01	32.01		5.85	
Fabrics	Warpwise	2	35.88†	278.75†	1690.69†	2718.15†	51.12†	20.64†
	Fillingwise			25.82†	1751.94*		86.52	
Wear periods	Warpwise	2	17.29†	0.53†	1565.75†	2258.19†	226.01†	13.04†
	Fillingwise			1.92†	2634.55†		347.86†	
Areas in trousers	Warpwise	2			110.93†		122.64†	
	Fillingwise				395.68†		238.58†	
Fabrics x periods	Warpwise	4	0.22	0.27	109.08†	76.00	11.34	0.82
	Fillingwise			0.21	98.39†		4.66	
Fabrics x areas	Warpwise	4			2.48		0.50	
	Fillingwise				8.14		2.42	
Periods x areas	Warpwise	4			6.46		6.99	
	Fillingwise				42.24*		10.90	
Fabrics x areas x periods	Warpwise	8			2.41		4.78	
	Fillingwise				4.05		3.00	
Error	Warpwise	16	0.28	0.13	7.59‡	26.91	5.79‡	2.38
	Fillingwise			0.25	7.67‡		4.56‡	

*"F" value exceeds the 5-percent level of significance.
†"F" value exceeds the 1-percent level of significance.
‡52 degrees of freedom.

From a cursory examination, changes in yarn count during wear appear unimportant, but many of these differences are shown to be highly significant (Table 5). Comparing the yarn counts among the three weights of fabric, variations between them are found to be such a case. The greatest differences between the fab-

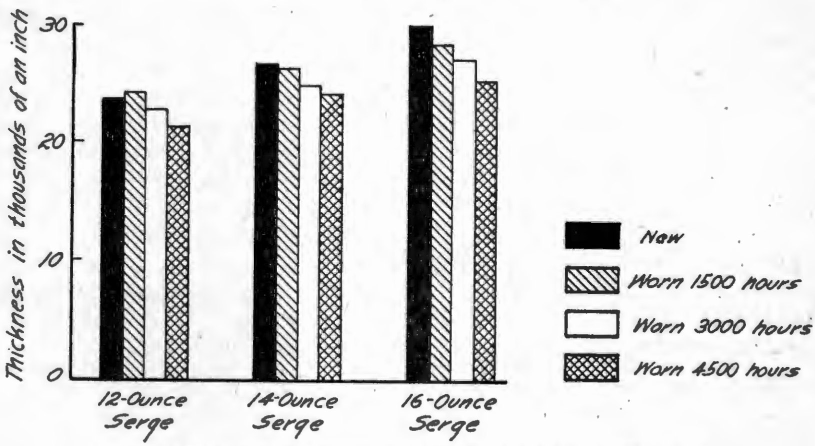

Figure 1. Thickness in thousandths of an inch of new and worn fabrics

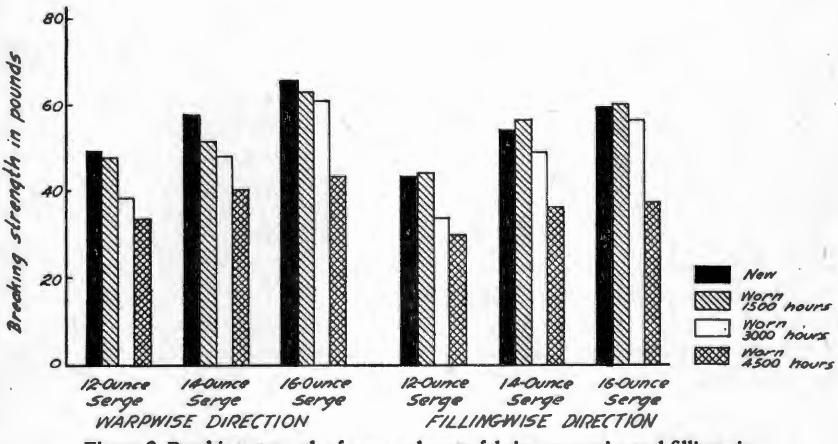

Figure 2. Breaking strength of new and worn fabrics, warpwise and fillingwise.

rics are shown to exist in the warpwise yarn count since the magnitude of this mean square is more than ten times as great as that for the fillingwise direction. Wear evidently resulted in considerable variation as shown by significant mean squares for the wear periods. The greater and more highly significant mean square for periods in the fillingwise direction bears out the findings cited above when comparisons were made of data listed in Table 4.

Breaking strength. Breaking strength values for the three areas of the trousers in each group are found in Appendix Table 1. Differences between mean values for each group appear in Table 4, and mean squares in Table 5.

Each wear period caused a definite loss in strength when compared with the new material with but three exceptions, all in the fillingwise direction. The 12-ounce serge broke at 49.25 pounds when new, and at 34.19 pounds at the end of the third wear period, in the warpwise direction. This was a loss of approximately 31 percent. Comparisons for the 14- and 16-ounce materials showed a similar trend, values decreasing from 57.75 to 40.13 pounds, and from 65.80 to 43.27 pounds, respectively. The loss for the 14-ounce material also amounted to 31 percent, whereas that for the 16-ounce fabric was 34 percent.

Corresponding fillingwise values decreased from 43.15 to 28.81 pounds, from 55.05 to 36.01 pounds and from 59.60 to 37.48 pounds for the 12-, 14-, and 16-ounce materials, respectively. These losses on a percentage basis are 33 percent for the 12-ounce, 35 percent for the 14-ounce and 37 percent for the 16-ounce material. Again the largest percentage of loss occurred in the 16-ounce fabric.

These changes are illustrated graphically in Figure 2, and are shown to be highly significant by the mean square for the interaction, fabrics x periods (Table 5). With continuing wear the strength that is left in fabrics becomes less and less until some minimum breaking strength value is reached when the fabric will no longer hold together. Such a breakdown actually takes place during wear at various locations in a garment, as evidenced by tears and holes.

Since a measurement of breaking strength requires that a measureable quantity of that property still must have been retained by the fabric, the changes in strength shown in this figure represent steps on the way to the end of serviceability. Had an assumption been made at the end of the second wear period that the residual strength would continue to decrease at the same rate as in the first two periods, the 16-ounce serge would have given every evidence of wearing far longer than the other two materials. The third period, however, disclosed a sharp decline in the strength of the 16-ounce fabric, and the residual strength in pounds was little more than that for the 14-ounce material.

From these results it would appear that the 14-ounce fabric might be the best selection, especially if the price were lower than that for the 16-ounce serge, since this lighter, and more comfortable material from the standpoint of weight, might be expected to give approximately the same amount of service as the 16-ounce fabric.

Mean values for measurements of breaking strength for a single area from the replicate trousers, after wear, may be accepted as typical for each area since the mean square for replication was not significant. Breaking strengths for the three weights of fabric varied greatly as shown by data in Appendix Table I, and the mean square for the fabrics indicates that these differences are highly significant, warpwise as well as fillingwise, for all three materials.

Breaking strength values were lower after each consecutive wear period for each weight of fabric and these differences again are highly significant in both directions of the cloth, although they vary in magnitude. Highly significant variation among the different areas of the trousers was not unexpected (see Table 5). From a brief study of the means for the top, middle, and bottom areas (Appendix Table I), it may be seen that in almost every instance the middle area sustained the greatest strength loss, while the bottom was affected least by actual wear.

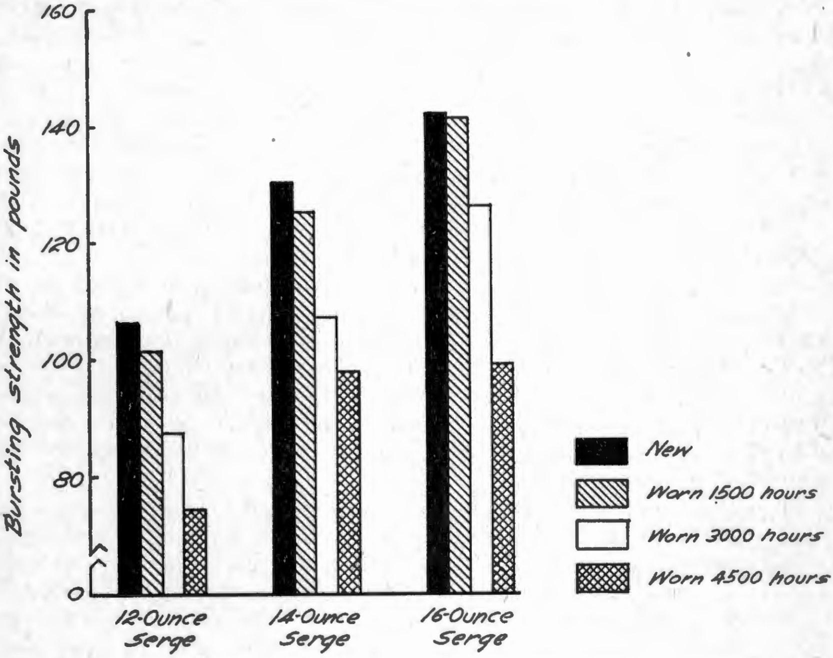

Figure 3. Bursting strength of new and worn fabrics.

Bursting strength. When comparing the bursting strength of fabrics worn during the first wear period with that of the new materials, values for the worn materials were slightly lower, although some individual differences were small, amounting to only 0.3 percent for the 16-ounce fabric. Thereafter a marked decrease in bursting strength was associated with increased wear, the strength of the 12-ounce fabric dropping from 106.50 pounds for the new material to 74.90 pounds after three periods of wear, a loss of 30 percent. The strength of the 14-ounce fabric decreased from 130.60 pounds when new to 98.40 pounds after wear, a 25 percent loss. The strength of the 16-ounce material dropped from 140.80 pounds to 99.65 pounds, a loss of 29 percent. According to the mean squares in Table 5, these differences among fabrics and periods are highly significant.

These changes are shown graphically in Figure 3. Again it is seen that after the first and second wear periods the 12- and 14-ounce fabrics show sizeable losses in bursting strength, while the 16-ounce material remains higher than the other two. After the third period, however, the bursting strength of the 16-ounce serge is almost the same as that of the 14-ounce. Bursting strength results also point to the 14-ounce fabric as having approximately the same amount of strength with less fabric weight and possibly lower cost.

Fabric elongation. Comparing values for elongation under breaking forces for the worn fabrics (Table 4) with those for the new material, wear seems to have caused varying losses in the ability of fabrics to stretch. With but one exception, increasingly lower elongation values are apparent in each consecutive wear period, both warpwise and fillingwise.

Variations among fabrics and wear periods are both highly significant. Since the mean square values for periods are at least four times as great as those for fabrics, it may be assumed that wear caused greater variation than fabric differences. The mean square for the areas in the trousers from which the samples were taken is also highly significant. Apparently the variation between areas is greater than that between the fabrics themselves, and less than that between wear periods. None of the interrelationships among the variables are significant.

Application of bursting forces produced decreased elongation values when all of the worn fabrics were compared with the new materials. Comparisons among the worn fabrics themselves show that values for wear period II are higher than for the other two periods for all three weights of fabric.

Interpreting these results statistically, it is seen from Table 5 that no variation occurred among replicates. High significance is shown for the variation among the three fabrics, whereas mean squares indicate that differences in wear periods were significant at the five percent level only.

Properties of the yarns after wear. *Yarn strength.* Comparing values for strength of yarns from the new fabrics with those for yarns from the worn fabrics shows differences which are recorded in Table 6. A decline in yarn strength after continued wear is evident. The warpwise decreases, in round numbers, at the end of the third period are from 268 to 222 grams for the 12-ounce material; from 369 to 312 for the 14-ounce fabric; and from 443 to 333 grams for the 16-ounce material. Fillingwise, these values are 241 to 157, 317 to 214, and 345 to 210 grams for the 12-, 14-, and 16-ounce fabrics, respectively.

All of these decreases, which are illustrated in Figure 4, were found to be highly significant. These lower values became apparent early in the experiment since all of the fabrics showed losses in yarn strength at the end of the first period of wear, these being highly significant for the 12- and 16-ounce materials. For the other two periods, yarn strength values for each fabric also were significantly lower than for the new materials.

In a comparison of these relationships with those for breaking strength and bursting strength of the worn fabrics (Figures 2 and 3), the 16-ounce material shows a pattern which is similar in all cases for cloth and yarn. The 12-ounce material gives evidence of some recovery in both warp and filling yarn strength after the third period. Such recovery is not shown in the case of fabric strength. This same trend is noted for the warps of the 14-ounce material.

In the analysis of variance for yarn measurements no significant variation was indicated among replications (Table 7). The mean squares for both fabrics and wear periods were highly significant in both directions. However, comparison of the size of the mean squares would indicate that the differences between the fabrics themselves are greater than those between the different wear periods. Evidently all fabrics did not react alike during each wear period, since the mean squares for the interaction of fabrics x periods were significant. These results indicate that considerable difference exists in the strength of yarns from the three fabrics and that wear definitely affects that strength.

Table 6. Differences Between Yarn Measurements for the Three Weights of Wool Serge, Comparing the Yarns from the New Fabrics and Those from the Worn Trousers[1]

Yarn measurements	Unit of measure	12-ounce serge Wear period			14-ounce serge Wear period			16-ounce serge Wear period		
		I	II	III	I	II	III	I	II	III
Yarn strength										
Warpwise	grams									
New		−20.5	−80.9	−46.7	−6.8	−62.8	−56.9	−23.6	−29.9	−109.9
Wear period I			−60.4	−26.2		−56.0	−50.1		−6.3	−86.3
Wear period II				+34.2			+5.9			−80.0
Fillingwise										
New		−41.9	−101.2	−84.5	−10.3	−74.3	−103.7	−25.6	−30.6	−135.1
Wear period I			−59.3	−42.6		−64.0	−93.4		−5.0	−109.5
Wear period II				+16.7			−29.4			−104.5
Yarn elongation	percent									
Warpwise										
New		+0.39	−0.65	−0.87	+1.35	−0.94	−1.71	+0.15	+0.41	−3.51
Wear period I			−1.04	−1.26		−2.29	−3.06		+0.26	−3.66
Wear period II				−0.22			−0.77			−3.92
Fillingwise										
New		−0.68	−1.19	−2.07	−0.56	−0.86	−2.94	+0.93	+0.88	−1.58
Wear period I			−0.51	−1.39		−1.42	−3.50		−0.05	−2.51
Wear period II				−0.88			−2.08			−2.46

[1]The plus sign indicates a gain and the minus sign a loss when comparisons are made with values for new materials or for preceding periods.

Yarn elongation. Elongation of the yarns from these materials was not affected by wear to the same extent as was observed for yarn strength. After the first wear period small gains were observed for all of the warp yarns, and for the fillings of the 16-ounce material. With but one exception, losses occurred in all other cases during each successive wear period.

Variation in yarn elongation of the fabrics is not highly significant (Table 7), but the variation between periods is shown to be significant at the one percent level.

Table 7. Mean Squares from the Analyses of Variance of Values for Properties of Yarns from the Three Weights of Wool Serge after Three Periods of Wear, and Their Significance as Shown by "F" Tests

Source of variation	Direction of test	Degrees of freedom	Strength	Elongation
Replication	Warpwise	2	62.11	0.14
	Fillingwise		311.87	0.09
Fabrics	Warpwise	2	66457.94†	6.12*
	Fillingwise		33071.86†	3.23*
Periods	Warpwise	2	7192.77†	16.22†
	Fillingwise		15078.08†	14.68†
Fabrics x periods	Warpwise	4	2679.15†	3.58
	Fillingwise		3019.51*	1.13
Error	Warpwise	16	464.84	1.28
	Fillingwise	—	871.72	0.72
	Total	26		

*"F" value exceeds the 5-percent level of significance.
†"F" value exceeds the 1-percent level of significance.

Effects of wear as noted from visual observations. Although data showing the effects of wear have been obtained by means of mechanical measurement, it may be of interest to note those changes in the fabrics which were apparent on visual inspection. Just as has been pointed out for some of the physical properties of these materials, observed effects of wear varied for the individual wearers, and were apparent on some trousers before they were noticeable on others.

Sixty-four notations of such evidences of wear were recorded. Although undoubtedly these were not complete, they constitute a sufficient number to indicate trends. Of these, 22 referred to some type of wear at the cuffs of the trousers; 15 to wear at the edges of the pockets; 15 to wear in the seat area; six to worn buttonholes; and the rest to wear at scattered locations.

Again, six of these 64 notations referred to evidences of wear observed during the first wear period; 42 to those observed during the second wear period; 17 to additional notes during the third period. It would seem that these garments stood up well under 1500 hours of wear. At the same time nearly two-thirds of all such notes referred to wear which was noticed first during the second period.

Considerable fraying and wear was observed on the cuffs and at the edge of the pockets. The latter became noticeable after 2400 hours of wear for trousers from each of the three weights of serge. Buttonholes appeared threadbare and worn by the time the garments had been used for 2700 hours. After the final wear period of 4500 hours, much mending and patching had become necessary on many of the trousers, yet some of them could have been worn longer. This possibility of longer

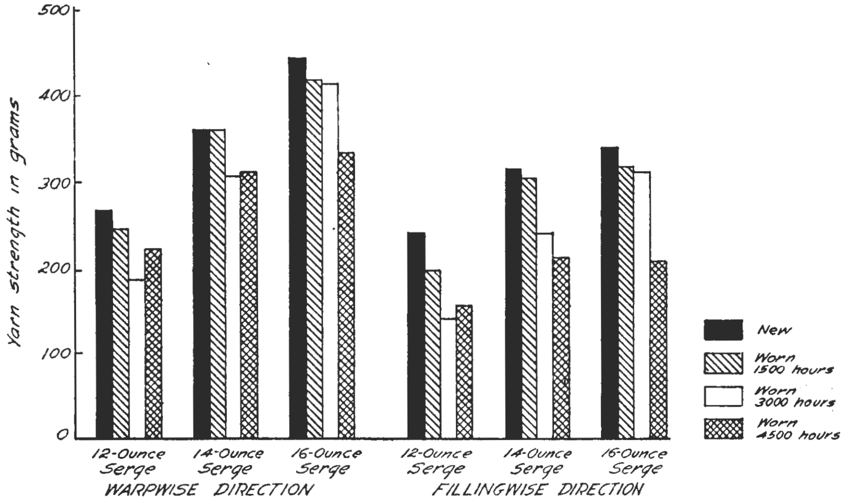

Figure 4. Yarn strength of new and worn fabrics, warpwise and fillingwise.

wear was true for the 12-ounce material as well as the heavier fabrics. Fewer notations of evidences of wear were recorded for the 14-ounce than for the 12- and 16-ounce serges.

In general these observations of evidences of wear indicate an approaching end-point of service, and parallel the changes in fabric properties which have been shown to result from wear. The few notations made during the first period check with the small changes in fabric properties. The marked decreases in weight, thickness, strength and elongation during the second period are reflected in the great increase in visual evidences of wear.

The sharp drop in strength of the 16-ounce serge after the third period is not indicated by the notations of observed wear for that period, although it could be possible that the beginning of wear seen during the second period in reality was associated with this final loss of strength. Also such a decrease in the strength of this piece of cloth might have been more clearly demonstrated had the trousers been worn as long as possible.

Effect of Light on the Fabrics

The destructive effect of "weathering," which is started while wool is still on the back of the sheep, is continued during the use of wool fabrics. When made into outer garments, these are exposed to sunlight to a varying degree. Therefore it is to be expected that the cloth of which the trousers were made doubtless suffered some further damage due to the action of ultra-violet rays which may affect the chemical and physical properties of the fiber. With sufficient exposure, wool fiber may become weakened, brittle, and more sensitive to alkalies *(6)*.

Table 8. Warpwise Breaking Strength of Three Weights of New All Wool Serge after Exposure to Artificial Light for Certain Periods of Time.

Hours of exposure	Warpwise Breaking Strength in Pounds 12-ounce	14-ounce	16-ounce
Unexposed	49.2	57.8	65.8
40	48.2	57.2	66.7
80	48.0	55.9	66.2
120	48.0	55.1	66.4
200	39.9	46.8	55.8
320	27.5	29.8	40.0
480	21.2	25.8	29.2
680	15.6	20.3	24.3

Since exposure to light could be one factor influencing the serviceability of these materials, new fabrics were exposed to the effects of light from an electric arc with a spectrum similar to that of sunlight. A current of moist cool air passing between the specimen and the arc is designed to protect the fabric from the effect of heat. The residual strength of the three weights of serge after exposure to such light for intervals from 40 to 680 hours is shown in Table 8.

No marked changes are noted for the first 120 hours of exposure. After 200 hours losses become markedly apparent and for each successive period of exposure, continued decreases in strength are evidenced. At the end of the 680-hour exposure period, breaking strength losses were approximately 68, 65 and 60 percent, respectively for the 12-, 14-, and 16-ounce materials, as compared with the unexposed fabrics. Both residual strength values and percent loss of strength give some indication that the 16-ounce fabric might stand up a little better under the effect of light than either the 12- or the 14-ounce material.

Although no record could be kept of the number of hours the trousers were exposed to sunlight, it is of interest to compare the warpwise strength of the fabrics after the completion of the third wear period with the warpwise strength of the materials after varying exposure to the light used under controlled conditions. If the values shown in Table 8 were plotted, it could then be seen that the residual strength of the 12- and 14-ounce fabrics after 4500 hours of wear might approximate that of the same materials after 250 hours of exposure to this light, while an equal amount of wear reduced the strength of the 16-ounce fabric to a level approximating 300 hours of exposure. Thus, although that portion of total wear which might be attributed to the destructive action of light cannot be determined from these data, it appears quite evident that light does contribute to a decrease in fabric strength and that unnecesary exposure to direct sunlight is not desirable.

Effect of Dry Cleaning and Storage Combined

In an attempt to determine the effect of dry cleaning and aging, the same procedures were used and the same measurements made as for the new materials. The samples which were used for studying the effects of dry cleaning were stored for periods equivalent to the periods of wear, and were removed and dry cleaned the same number of times as the trousers. At the end of the first period, which was equivalent to 1500 hours of wear, these samples had been dry cleaned five times;

at the end of the second period (3000 hours) they had been cleaned 10 times; and at the end of the third period (4500 hours), 15 times. For the sake of brevity, these fabrics are referred to simply as dry cleaned. Values for fabric and yarn properties are summarized in Appendix Table III.

Properties of the fabrics. *Weight per square yard.* The weight per square yard of the new materials, in round numbers, was 8, 9 and 10 ounces for the 12-, 14-, and 16-ounce fabrics, respectively. The weight after cleaning and storage remained approximately the same as that of the new materials, and did not change appreciably throughout the entire series of dry cleanings (Table 9). It is evident, therefore, that fabric weight was not affected by dry cleaning and storage.

Thickness. In all cases the fabrics which had been dry cleaned five times were thinner than the new materials. As the dry cleaning process was continued the fabrics increased in thickness until at the end of 15 dry cleanings the increases varied from 0.7 to 1.5 thousandths of an inch over the thickness of the materials which had been dry cleaned five times; and for the 12- and 14-ounce materials these values exceeded the thickness of the new materials by 4.0 and 1.6 percent. However, it must be remembered that storage constituted a part of this treatment.

Relationships among the variates have been determined for the dry cleaned and stored fabrics. The results appear in Table 10. There is considerable variation in thickness among the fabrics themselves since the mean square for fabrics is highly significant. Thickness measurements after each period of dry cleaning showed less variation, and although the mean square is small, it does reach the five percent level of significance.

Yarn count. Variations in yarn count as shown in Table 9 are small. Comparing the yarn count on the new fabrics with that for the materials which had been dry cleaned five times, it was found that in all but one case the count was slightly lower after dry cleaning. As dry cleaning was continued yarn count increased slightly, indicating some slight shrinkage in all three weights of fabric. Highly significant variation in yarn count among the fabrics is indicated by the mean square for fabrics, greater variation being shown in the number of warps per inch than in the number of fillings. Periods of storage and number of dry cleanings also show highly significant results.

Breaking strength. Breaking strength values for the three weights of serge show that after dry cleaning five times the warpwise strength values were lower than those for the new materials, but a similar comparison in the fillingwise direction showed a gain for the 14- and 16-ounce materials. As the dry cleaning process was continued, however, every fabric showed increased resistance to breaking forces, warpwise and fillingwise, increases ranging from 0.10 to 3.45 pounds. These changes are illustrated graphically in Figure 5. These may have resulted from small amounts of shrinkage. Although shrinkage due to dry cleaning characteristically is not as great as the shrinkage due to sponging, increases in yarn count, both warpwise and fillingwise, as shown in Table 9, suggest that some shrinkage did occur during the dry cleaning process.

The three weights of fabric varied considerably in breaking strength as indicated by the highly significant mean square for fabrics shown in Table 10. Breaking strength values for periods of storage and dry cleaning also showed variations

Table 9. Differences Between the Physical Measurements of Three Weights of Wool Serge, Comparing the New Fabrics and Those Which Have Been Stored and Dry Cleaned.[1]

Fabric property	Unit of measure	12-ounce serge Number of Dry Cleanings 5	10	15	14-ounce serge Number of Dry Cleanings 5	10	15	16-ounce serge Number of Dry Cleanings 5	10	15
Weight per sq. yd.	ounces									
New		+0.19	+0.34	+0.27	+0.39	+0.48	+0.48	+0.44	+0.53	+0.50
Cleaned 5 times			+0.15	+0.08		+0.09	+0.09		+0.09	+0.06
Cleaned 10 times				−0.07			0.00			−0.03
Thickness	1/1000 in.									
New		−0.20	+0.45	+0.95	−1.05	−0.70	+0.45	−1.85	−1.55	−1.15
Cleaned 5 times			+0.65	+1.15		+0.35	+1.50		+0.30	+0.70
Cleaned 10 times				+0.50			+1.15			+0.40
Yarn count	number per in.									
Warpwise										
New		−1.00	−0.20	+0.60	−0.90	0.00	+1.20	−1.50	−1.00	+0.40
Cleaned 5 times			+0.80	+1.60		+0.90	+2.10		+0.50	+1.90
Cleaned 10 times				+0.80			+1.20			+1.40
Fillingwise										
New		+0.30	+1.40	+1.30	−1.30	−0.20	−0.30	−1.70	−0.90	−0.30
Cleaned 5 times			+1.10	+1.00		+1.10	+1.00		+0.80	+1.40
Cleaned 10 times				−0.10			−0.10			+0.60
Breaking strength	pounds									
Warpwise										
New		−0.95	−0.85	+0.30	−3.50	−2.50	−0.65	−1.75	+0.15	+0.80
Cleaned 5 times			+0.10	+1.25		+1.00	+2.85		+1.90	+2.55
Cleaned 10 times				+1.15			+1.85			+0.65
Fillingwise										
New		−0.40	+2.25	+3.05	+1.65	+3.35	+3.85	+0.80	+2.10	+4.10
Cleaned 5 times			+2.65	+3.45		+1.70	+2.20		+1.30	+3.30
Cleaned 10 times				+0.80			+0.50			+2.00
Bursting strength	pounds									
New		−0.75	+1.40	+1.70	−5.25	−4.30	−3.40	+3.90	−2.35	+5.00
Cleaned 5 times			+2.15	+2.45		+0.95	+1.85		−6.25	+1.10
Cleaned 10 times				+0.30			+0.90			+7.35

[1]The plus sign indicates a gain and the minus sign a loss when comparisons are made with values for new materials or for preceding periods.

Table 9, continued. Differences Between the Physical Measurements of Three Weights of Wool Serge, Comparing the New Fabrics and Those Which Have Been Stored and Dry Cleaned.[1]

Fabric property	Unit of measure	12-ounce serge Number of Dry Cleanings			14-ounce serge Number of Dry Cleanings			16-ounce serge Number of Dry Cleanings		
		5	10	15	5	10	15	5	10	15
Tearing strength	pounds									
Warpwise										
New		−0.65	−1.00	−1.10	−1.25	−2.15	−2.75	−0.85	−1.70	−1.85
Cleaned 5 times			−0.35	−0.45		−0.90	−1.50		−0.85	−1.00
Cleaned 10 times				−0.10			−0.60			−0.15
Fillingwise										
New		−0.25	−0.40	−0.65	+0.15	−0.40	−0.85	−0.45	−0.95	−0.95
Cleaned 5 times			−0.15	−0.40		−0.55	−1.00		−0.50	−0.50
Cleaned 10 times				−0.25			−0.45			0.00
Elongation, breaking test	percent									
Warpwise										
New		−0.67	+5.66	+3.66	−3.33	0.00	+1.66	−3.33	+3.01	−0.33
Cleaned 5 times			+6.33	+4.33		+3.33	+4.99		+6.34	+3.00
Cleaned 10 times				−2.00			+1.66			−3.34
Fillingwise										
New		−3.66	0.00	+1.67	−7.99	−5.00	−3.33	−6.00	−2.67	−1.34
Cleaned 5 times			+3.66	+5.33		+2.99	+4.66		+3.33	+4.66
Cleaned 10 times				+1.67			+1.67			+1.33
Elongation, bursting test	percent									
New		−4.28	+3.15	+4.86	−11.42	−5.14	−8.00	−7.13	−1.13	−1.71
Cleaned 5 times			+7.43	+9.14		−6.28	+3.42		+6.00	+5.42
Cleaned 10 times				+1.71			−3.86			−0.58
Shrinkage	percent									
Warpwise										
New		−1.34	−2.28	−2.40	−0.78	−1.62	−2.44	−1.62	−2.55	−2.20
Cleaned 5 times			−0.95	−1.07		−0.84	−1.66		−0.93	−0.58
Cleaned 10 times				−0.12			−0.82			+0.35
Fillingwise										
New		+0.83	+0.12	+0.12	+1.16	+1.07	+1.07	+0.33	−0.01	+0.57
Cleaned 5 times			−0.61	−0.61		−0.09	−0.09		−0.34	+0.24
Cleaned 10 times				0.00			0.00			+0.58

[1]The plus sign indicates a gain and the minus sign a loss when comparisons are made with values for new materials or for preceding periods.

which were significant. A comparison of mean squares for fabrics and periods indicates that differences in breaking strength among fabrics were much greater than between periods.

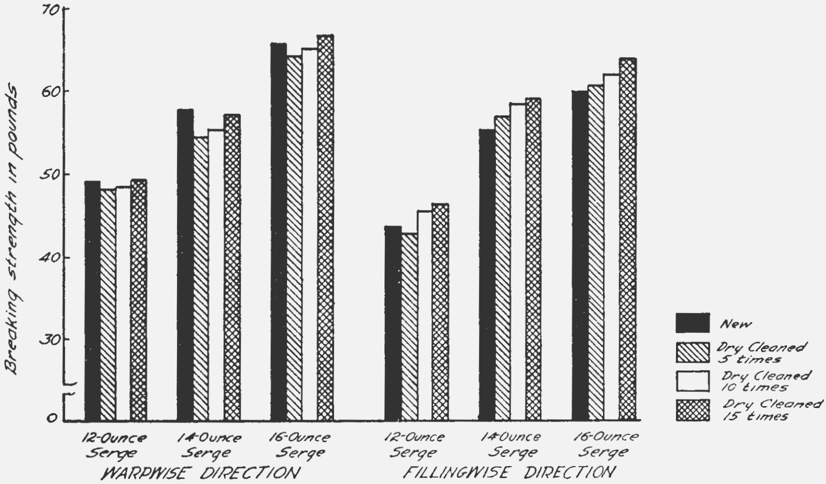

Figure 5. Breaking strength of new, and dry cleaned and stored fabrics, warpwise and fillingwise.

Bursting strength. Bursting strength values for the 12- and 14-ounce fabrics after dry cleaning five times were lower than those for the new materials, while the 16-ounce material showed a gain. With but one exception, all three fabrics increased somewhat in bursting strength after suceeding periods of storage and dry cleaning. As with breaking strength, the increased yarn count shown in Table 9 would indicate some shrinkage which might account for the increases in bursting strength noted during the second and third periods.

Highly significant variation in bursting strength is noted among fabrics, but the mean square for periods does not indicate significant differences. It is probable that the changes noted in Table 9 are within the range of errors of random sampling. Apparently dry cleaning and storage did not exert any marked influence upon the bursting strength of these materials.

Tearing strength. With but two exceptions the tearing strength values for the three weights of serge show a progressive decrease as the result of dry cleaning and storage. These losses vary from 0.10 to 2.75 pounds in the warpwise direction, and from 0.15 to 1.00 pounds in the fillingwise direction, maximum losses occurring in the 14-ounce fabric in both instances.

Highly significant variation among fabrics is indicated in Table 10. Periods of dry cleaning and storage effected some change in tearing strength although these variations were significant at the five percent level only.

Fabric elongation. Comparing data for elongation due to application of breaking forces for dry cleaned and stored fabrics (Table 9) with those for the new materials, values at the end of the first period of dry cleaning are lower than those for the new in every case. Thereafter increases appear at the end of each period.

Highly significant variation in elongation due to breaking forces is observed for the fabrics, in the fillingwise direction only. The mean square for periods also is highly significant fillingwise, whereas warpwise only the five percent level is attained.

Elongation due to bursting forces showed values for the dry cleaned and stored fabrics which were lower after the first period than were those for the new materials. These lower values continue through the two succeeding periods for the 14- and 16-ounce pieces, whereas the 12-ounce fabric shows increases which result in values that are higher than those for the new materials. No significant variation in this property among fabrics in indicated (Table 10). The periods of storage and dry cleaning produced a significant effect on elongation when bursting forces were applied.

Table 10. Mean Squares from the Analyses of Variance of Values for Certain Properties of Three Weights of Wool Serge Which Have Been Stored and Dry Cleaned 5, 10, and 15 Times, and Their Significance as Shown by "F" Tests.

Source of variation	Direction of test	Degrees of freedom	Thickness	Yarn count	Breaking strength	Bursting strength	Tearing strength	Elongation Breaking test	Elongation Bursting test
Fabrics	Warpwise	2	12.90†	82.93†	213.85†	957.19†	3.62†	3.79	0.57
	Fillingwise			7.75†	242.14†		4.25†	17.13†	
Periods	Warpwise	2	0.95*	2.65†	3.70*	6.23	0.77*	23.41*	39.71*
	Fillingwise			1.15†	6.83†		0.31*	18.67†	
Error	Warpwise	4	0.06	0.03	0.32	6.06	0.07	1.79	2.37
	Fillingwise			0.04	0.26		0.03	0.05	

*"F" value exceeds the 5-percent level of significance.
†"F" value exceeds the 1-percent level of significance.

Shrinkage from sponging. All three weights of fabric showed a lower percentage of shrinkage warpwise when sponged after dry cleaning and storing than was observed after the new materials had been sponged. These decreases varied from 0.12 to 2.55 percent. Fillingwise shrinkage of the dry cleaned and stored fabrics in general was greater than that of the new materials after sponging, these changes varying from 0.83 to 1.16 percent.

PROPERTIES OF YARNS FROM DRY CLEANED AND STORED MATERIALS. *Yarn strength.* The first five dry cleanings did not have a consistent effect upon yarns from the three serges, since it may be seen (Table 11) that some lost in strength whereas others showed small gains. After the second period yarns from the 14- and 16-ounce materials showed increases in strength over those from the new materials, and at the end of the third period the yarns from all three fabrics were stronger than those from the new materials.

Large variations in the strength of yarns from the three fabrics are indicated in Table 12, but only warpwise variation for periods was significant, and this at the five percent level.

Yarn elongation. According to differences between the means for yarn measurements, at least small gains in elongation seem to have occurred quite consistently as the process of dry cleaning and storing was continued. However, none of

Table 11. Differences Between Yarn Measurements for the Three Weights of Wool Serge, Comparing the Yarns from the New Fabrics and Those from Fabrics Which Have Been Stored and Dry Cleaned.[1]

		12-ounce serge Number of Dry Cleanings			14-ounce serge Number of Dry Cleanings			16-ounce serge Number of Dry Cleanings		
Yarn measurements	Unit of measure	5	10	15	5	10	15	5	10	15
Yarn strength	grams									
Warpwise										
New		+4.8	—19.3	+8.2	—12.0	+30.8	+21.0	—0.6	+11.4	+16.8
Cleaned 5 times			—24.1	+3.4		+42.8	+33.0		+12.0	+17.4
Cleaned 10 times				+27.5			—9.8			+5.4
Fillingwise										
New		—14.0	—16.7	+27.6	+7.4	+40.3	+52.8	+3.8	+23.2	+41.4
Cleaned 5 times			—2.7	+41.6		+32.9	+45.4		+19.4	+37.6
Cleaned 10 times				+44.3			+12.5			+18.2
Yarn elongation	percent									
Warpwise										
New		+2.02	+2.35	+2.26	+0.90	+3.26	+1.67	+0.63	+1.34	+1.53
Cleaned 5 times			+0.33	+0.24		+2.36	+0.77		+0.71	+0.90
Cleaned 10 times				—0.09			—1.59			+0.19
Fillingwise										
New		+0.79	+2.04	+2.92	—0.20	+3.53	+2.79	+0.94	+2.53	+2.57
Cleaned 5 times			+1.25	+2.13		+3.73	+2.99		+1.59	+1.63
Cleaned 10 times				+0.88			—0.74			+0.04

[1]The plus sign indicates a gain and the minus sign a loss when comparisons are made with values for new materials or for preceding periods.

these were highly significant, although again the filling yarns are signicantly more extensible at the five percent level when comparing periods.

Table 12. Mean Squares from Analyses of Variance of Values for Properties of Yarns from the Three Weights of Wool Serge Which Have Been Stored and Dry Cleaned 5, 10, and 15 Times, and Their Significance as Shown by "F" Tests

Source of variation	Direction of test	Degrees of freedom	Strength	Elongation
Fabrics	warpwise	2	26527.94†	1.72
	fillingwise		14371.24†	1.39
Periods	warpwise	2	242.81	0.97
	fillingwise		1311.68*	4.93*
Error	warpwise	4	282.05	0.37
	fillingwise		104.28	0.49
	Total	8		

*"F" value exceeds the 5-percent level of significance.
†"F" value exceeds the 1-percent level of significance.

Effect of Storage alone

In order to show what portion of the effects of wear, which have been discussed in a preceding section, should be attributed to aging or storage, samples of the new fabrics were placed in storage for periods equivalent to the trouser wearing periods. For the sake of simplicity in identifying the stored fabrics, these have been referred to as Stored Fabrics I, which correspond to the trousers worn 1500 hours; Stored Fabrics II, to those worn 3000 hours; and Stored Fabrics III, to those worn 4500 hours. Values for fabric and yarn properties after three periods of storage are shown in Appendix Table IV.

Influence of storage on fabric properties. *Weight per square yard.* The weight per square yard of the fabrics after storage remained approximately the same as that of the new materials and of those which were dry cleaned and stored, although small variations can be observed from the differences given in Table 13, these being increases in more than half of the cases.

Thickness. Thickness of the fabrics was not affected to a significant extent by storage. Comparing the stored fabrics with the new materials, it is found that the stored are from two to five thousandths of an inch thinner than the new materials, but the mean squares listed in Table 14 indicate these differences are not of statistical significance.

Yarn count. The number of yarns per inch in each fabric might have been expected to remain the same during storage periods. However, Table 13 shows that small decreases did occur in some cases, those in the fillingwise direction being significant (Table 14).

The differences in yarn count of the fabrics themselves varied significantly, and this is in keeping with the observed character of the new materials. Again the differences in count among storage periods were not nearly so large as those among the fabrics themselves.

Breaking strength. Changes in breaking strength resulting from storage appear small, according to values in Table 13. On a percentage basis, they range from

Table 13. Differences Between the Physical Measurements of Three Weights of Wool Serge, Comparing the New Fabrics and Those Which Have Been Stored.[1]

Fabric property	Unit of measure	12-ounce serge Storage Periods I	II	III	14-ounce serge Storage Periods I	II	III	16-ounce serge Storage Periods I	II	III
Weight per sq. yd.	ounces									
New		—0.05	—0.02	+0.02	+0.30	+0.40	+0.22	+0.19	+0.07	+0.17
Stored I			+0.03	+0.07		+0.10	—0.08		—0.12	—0.02
Stored II				—0.04			—0.18			+0.10
Thickness	1/1000 in.									
New		—4.75	—4.35	—2.00	—3.40	—3.55	—4.35	—5.50	—5.85	—4.90
Stored I			+0.40	+2.75		—0.15	—0.95		—0.35	+0.60
Stored II				+2.35			—0.80			+0.95
Yarn count	number									
Warpwise	per in.									
New		—2.30	—1.10	—1.30	—0.40	—0.70	+0.10	—1.60	—1.50	—1.30
Stored I			+1.20	+1.00		—0.30	+0.50		+0.10	+0.30
Stored II				—0.20			+0.80			+0.20
Fillingwise										
New		—1.30	—1.00	—0.90	—2.20	—1.40	—1.40	—2.60	—1.80	—1.90
Stored I			+0.30	+0.40		+0.80	+0.80		+0.80	+0.70
Stored II				+0.10			0.00			—0.10
Breaking strength	pounds									
Warpwise										
New		—1.45	+0.25	—0.30	—2.30	—0.05	—1.65	—1.00	+1.80	+0.35
Stored I			+1.70	+1.15		+2.25	+0.65		+2.80	+1.35
Stored II				—0.55			—1.60			—1.45
Fillingwise										
New		+0.40	+3.35	+1.60	+1.65	+3.95	+2.95	—0.60	+4.50	+0.30
Stored I			+2.95	+1.20		+2.30	+1.30		+5.10	+0.90
Stored II				—1.75			—1.00			—4.20
Bursting strength	pounds									
New		—4.20	—3.75	+0.15	—5.70	—1.40	—8.90	—0.65	—3.35	+3.00
Stored I			+0.45	—4.35		+4.30	—3.20		—2.70	+3.65
Stored II				+3.90			—7.50			+6.35

[1]The plus sign indicates a gain and the minus sign a loss when comparisons are made with values for new materials or for preceding periods.

Table 13. (Continued) Differences Between the Physical Measurements of Three Weights of Wool Serge, Comparing the New Fabrics and Those Which Have Been Stored

Fabric property	Unit of measure	12-ounce serge Storage Periods I	II	III	14-ounce serge Storage Periods I	II	III	16-ounce serge Storage Periods I	II	III
Tearing strength	pounds									
Warpwise										
New		—0.15	—0.35	—0.10	—0.45	—0.80	—0.45	—0.20	—1.00	—0.30
Stored I			—0.20	+0.05		—0.35	0.00		—0.80	—0.10
Stored II				+0.25			+0.35			+0.70
Fillingwise										
New		+0.35	+0.20	+0.80	+0.85	+0.20	+0.80	+0.20	—0.25	+0.25
Stored I			—0.15	+0.45		—0.65	—0.05		—0.45	+0.05
Stored II				+0.60			+0.60			+0.50
Elongation, breaking test	percent									
Warpwise										
New		—4.34	—3.01	—4.34	—4.34	—5.00	—2.67	—4.66	—5.33	—4.33
Stored I			+1.33	0.00		—0.66	+1.67		—0.67	+0.33
Stored II				—1.33			+2.33			+1.00
Fillingwise										
New		—5.00	—3.00	—3.00	—8.33	—7.99	—5.66	—7.67	—5.34	—3.00
Stored I			+2.00	+2.00		+0.34	+2.67		+2.33	+4.67
Stored II				0.00			+2.33			+2.34
Elongation, bursting test	percent									
New		+4.29	+3.72	+4.29	—10.00	—4.00	—6.28	—5.70	+0.01	+1.15
Stored I			—0.57	0.00		+6.00	+3.72		+5.71	+6.85
Stored II				+0.57			—2.28			+1.14
Shrinkage	percent									
Warpwise										
New		+0.28	+0.49	+0.14	+0.22	+0.58	+0.34	+0.33	+1.15	—0.12
Stored I			+0.11	—0.14		+0.36	+0.12		+0.82	—0.45
Stored II				—0.35			—0.24			—1.27
Fillingwise										
New		+1.84	+0.94	+1.05	+1.55	+1.30	+1.41	+0.83	+0.80	+0.57
Stored I			—0.90	—0.79		—0.25	—0.14		—0.03	—0.26
Stored II				+0.11			+0.11			—0.23

[1]The plus sign indicates a gain and the minus sign a loss when comparisons are made with values for new materials or for preceding periods.

a loss of four percent to an increase of three percent warpwise, and from a loss of one percent to a gain of eight percent fillingwise. About half of the changes are increases in strength over that for the new materials as may be seen in Figure 6. It is apparent also that Stored Fabrics II gave higher breaking strength values than did the fabrics for the other two periods.

Differences among the strength values for the three weights of serge are large and highly significant. Variability in strength after each period of storage does not show the same degree of significance. This would seem to indicate that for these fabrics the amount of aging, or the duration of the storage period, is not a vital factor in the strength of the garment.

Bursting strength. Bursting strength values, in general, were somewhat lower after storage, but these differences are not statistically significant according to the mean square for periods (Table 14). However, the bursting strengths of these serges after storage continue to vary with high significance when comparing the three weights of fabric. Apparently the inherent differences among the fabrics had greater effect upon bursting strength than the aging effect resulting from the three storage periods.

Tearing strength. Tearing strength (Table 13) shows some small losses during the first two periods of storage, but gains are observed to have taken place during the last period. Differences in tearing strength among the three fabrics are highly significant, but for periods only the five percent level of significance is attained (Table 14). Again, it is indicated that far less variation resulted from the various periods of storage than from differences among the fabrics themselves.

Fabric elongation. Elongation due to application of breaking forces disclosed some tendency toward a loss of stretching ability which appears to have resulted from storage.

Differences in fabric elongation due to breaking forces were more pronounced in the fillingwise direction than they were warpwise for the fabrics as well as for the storage periods. The mean squares in Table 14 indicate that this tendency is statistically significant.

Elongation resulting from bursting forces gave values after storage that in general were larger than those for the new 12- and 16-ounce fabrics, but lower than that for the 14-ounce fabric. Comparisons between periods show both losses and gains in these elongation values. No significant differences were found among fabrics, or for storage periods. All other properties which have been analyzed have shown significant differences among the fabrics themselves, but elongation from the application of bursting forces did not follow the trend in this respect.

Shrinkage from sponging. Shrinkage values changed very little as a result of the aging of the fabrics. In all cases the change is less than two percent, the majority of cases showing a loss or a gain of less than one percent.

Influence of storage on yarn properties. *Yarn Strength.* Although some differences in strength are to be noted when comparing yarns from the new fabrics with yarns from materials stored for various lengths of time and among the latter (Table 15), the only significant differences among these strength values are for yarns from the three weights of fabric (Table 16). This is true for fillings as well as for warps. Varying periods of storage seemed to have no significant effect upon yarn strength.

Table 14. Mean Squares from the Analyses of Variance of Values for Certain Properties of Three Weights of Wool Serge after Three Periods of Storage, and Their Significance as Shown by "F" Tests.

Source of variation	Direction of test	Degrees of freedom	Thickness	Yarn count	Breaking strength	Bursting strength	Tearing strength	Elongation Breaking test	Elongation Bursting test
Fabrics	warpwise	2	15.02*	69.45†	229.04†	1012.35†	5.39†	14.05*	1.37
	fillingwise			3.30†	217.94†		4.42†	26.38†	
Periods	warpwise	2	0.67	0.27	3.80†	1.93	0.20*	0.44	13.12
	fillingwise			0.40*	9.28*		0.26*	7.27*	
Error	warpwise	4	1.02	0.16	0.13	14.05	0.03	0.92	4.82
	fillingwise			0.02	0.83		0.02	0.81	

*"F" value exceeds the 5-percent level of significance.
†"F" value exceeds the 1-percent level of significance.

Table 15. Differences Between Yarn Measurements for Three Weights of Wool Serge, Comparing Yarns from New Materials and Those from Fabrics Which Have Been Stored.[1]

Yarn measurements	Unit of measure	12-ounce serge Storage Periods I	II	III	14-ounce serge Storage Periods I	II	III	16-ounce serge Storage Periods I	II	III
Yarn strength	grams									
Warpwise										
New		—8.8	—25.3	+1.8	+13.8	—10.7	+19.9	—14.0	+11.6	+6.0
Stored I			—16.5	+10.6		—24.5	+6.1		+25.6	+20.0
Stored II				+27.1			+30.6			—5.6
Fillingwise										
New		—16.4	—32.1	+4.9	+26.0	—1.9	+35.2	+6.4	+15.9	+8.8
Stored I			—15.7	+21.3		—27.9	+9.2		+9.5	+2.4
Stored II				+37.0			+37.1			—7.1
Yarn elongation	percent									
Warpwise										
New		—0.10	+2.86	+1.82	+3.29	+3.44	+1.44	+1.33	+2.32	+0.47
Stored I			+2.96	+1.92		+0.15	—1.85		+0.99	—0.86
Stored II				—1.04			—2.00			—1.85
Fillingwise										
New		+1.09	+1.81	+1.42	+3.32	+4.57	+2.10	+2.86	+2.96	+2.07
Stored I			+0.72	+0.33		+1.25	—1.22		+0.10	—0.79
Stored II				—0.39			+2.47			—0.89

[1]The plus sign indicates a gain and the minus sign a loss when comparisons are made with values for new materials or for preceding periods.

Table 16. Mean Squares from the Analyses of Variance of Values for Properties of Yarns from the Three Weights of Wool Serge after Three Periods of Storage, and Their Significance as Shown by "F" Tests

Source of variation	Direction of test	Degrees of freedom	Strength	Elongation
Fabrics	warpwise	2	26850.40†	6.36
	fillingwise		14504.79†	6.04
Periods	warpwise	2	238.80	2.30
	fillingwise		374.12	1.18
Error	warpwise	4	195.56	1.03
	fillingwise	—	184.19	0.36
	Total	8		

†"F" value exceeds the 1-percent level of significance.

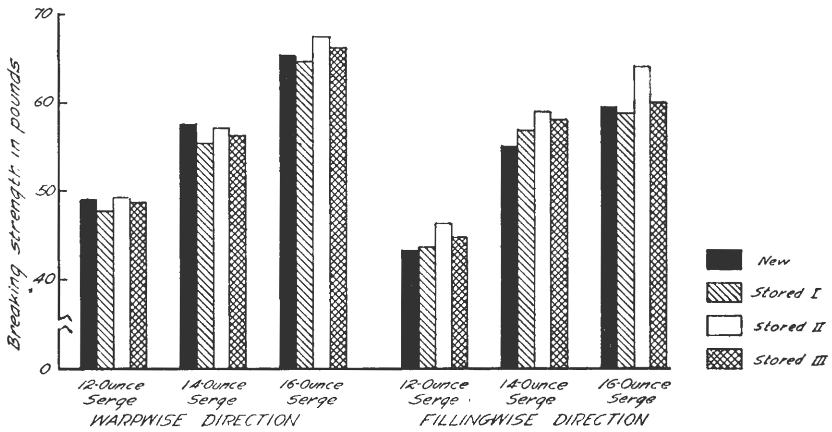

Figure 6. Breaking strength of new and stored fabrics, warpwise and fillingwise.

Yarn elongation. Values for this property seemed to show gains in several comparisons, but these differences are not statistically significant.

Effect of Dry Cleaning Alone

In order to determine the effect of dry cleaning alone, values showing changes due to the effect of storage (Table 13) have been subtracted from similar values showing changes found for the stored and dry cleaned samples (Table 9). The net results of these subtractions (Table 17) exclude differences in values for the new materials and are not presented as absolute values. However, they do show trends and give approximations of changes in these fabrics which probably are due to the effects of dry cleaning only.

Weight per square yard. Although the weight per square yard of both the stored, and the dry cleaned and stored fabrics remained the same, in round numbers, as those for the new materials, small changes did occur as can be seen from Tables 9 and 13. Therefore, as a result of dry cleaning only, increases are shown in every instance for all three weights of materials (Table 17).

These values do not lend themselves to statistical evaluation, yet they do indicate that the sum total effect of dry cleaning is to increase weights slightly in all cases. These increases ranged from one-fourth to approximately one-half ounce per square yard.

Thickness. Dry cleaning alone apparently increased thickness for all three fabrics (Table 17), increases varying from 2.4 to 4.8 thousandths of an inch. Thus it would appear that dry cleaning doubtless caused some shrinkage, an effect which would compensate for the loss in thickness resulting from storage or aging, since all of the dry cleaned values are higher than those for the stored materials. These differences appear to be independent of the number of dry cleanings.

Yarn count. No change in yarn count was evident after storage, but gains of 0.1 to 2.4 yarns per inch are shown in Table 17 to have resulted from dry cleaning.

Table 17. The Difference Between the Effect of Dry Cleaning and of Storing at End of Each Period as Shown by Differences Between Fabrics Which Were Stored and Dry Cleaned and Those Which Were Stored Only[1]

Property measured	Unit of measure	Periods	12-ounce serge	14-ounce serge	16-ounce serge
Weight per sq. yd	ounces	I	+0.24	+0.09	+0.25
		II	+0.36	+0.08	+0.46
		III	+0.25	+0.26	+0.33
Thickness	1/1000 in.	I	+4.55	+2.35	+3.65
		II	+4.80	+2.85	+4.30
		III	+2.95	+4.80	+3.75
Yarn count	number	I	+1.3	—0.5	+0.1
warps	per inch	II	+0.9	+0.7	+0.5
		III	+1.9	+1.1	+1.7
fillings		I	+1.6	+0.9	+0.9
		II	+2.4	+1.2	+0.9
		III	+2.2	+1.1	+1.6
Breaking strength	pounds	I	+0.50	—1.20	—0.75
warpwise		II	—1.10	—2.45	—1.65
		III	+0.60	+1.00	+0.45
fillingwise		I	—0.80	0.00	+1.40
		II	—1.10	—0.60	—2.40
		III	+1.45	+0.90	+3.80
Bursting strength	pounds	I	+3.45	+0.45	+4.55
		II	+5.15	—2.90	+1.00
		III	+1.55	+5.50	+2.00
Tearing strength	pounds	I	—0.50	—0.80	—0.65
warpwise		II	—0.65	—1.35	—0.70
		III	—1.00	—2.30	—1.55
fillingwise		I	—0.60	—0.60	—0.65
		II	—0.60	—0.60	—0.70
		III	—1.45	—1.65	—1.20
Elongation—breaking test	percent	I	+3.67	+1.01	+1.33
warpwise		II	+8.67	+5.00	+8.34
		III	+8.00	+4.33	+4.00
fillingwise		I	+1.34	+0.34	+1.67
		II	+3.00	+2.99	+2.67
		III	+4.67	+2.33	+1.66
Elongation—bursting test	percent	I	—8.57	—1.42	—1.43
		II	—0.57	—1.14	—1.14
		III	+0.57	—1.72	—2.86

[1]The plus sign indicates a gain with dry cleaning and the minus sign a loss with dry cleaning when comparisons are made with values for fabrics which were stored only.

Again, it is felt that these changes probably are due to shrinkage resulting from dry cleaning.

Breaking strength. Dry cleaning may have caused both gains and losses in breaking strength, but at the end of the third period small gains, which range from 0.45 to 3.80 pounds, appear in every instance (Table 17). Such gains could result from the shrinkage and small increase in number of yarns per inch cited previously in connection with thickness and yarn count.

Bursting strength. In general, dry cleaning alone appears to have caused increases in bursting strength which appear not to be related to the amount of dry cleaning.

Tearing strength. Resistance to tearing strenght seems to be reduced slightly as a result of dry cleaning alone. This increase in ease of tearing appears rather constant for the first two periods, but is markedly greater for the third period.

Fabric elongation. The percent elongation resulting from application of breaking forces has been shown to decrease as a result of storage. Dry cleaning alone apparently tends to restore this decrease since all of the values for the dry cleaned and stored materials are higher than for those which were stored only. These differences seem unrelated to the periods of treatment.

Elongation due to bursting forces, on the other hand, showed decreases rather than increases as a result of dry cleaning alone. These are not progressive, and again the differences seem unrelated to periods.

Effect of Wear alone

The preceding sections have dealt with the combined effects of wear, cleaning, and aging on the trousers, and with the effects of storage and of dry cleaning on the fabrics. Since all of these factors are integral parts of the physical conditions to which garments are subjected when worn over a period of time, they contribute to or influence the results obtained when the physical properties of the fabric in a garment are measured at the end of any specified period of wear.

In order to picture more precisely the effect of wear alone the effects of storage and dry cleaning have been eliminated by subtraction, and the net results are listed in Table 18.

Influence of wear alone on fabric properties. *Weight per square yard.* The effect of wear alone was a slight gain in weight at the end of the first wear period; losses varying from one-half to three-fourths of an ounce per square yard were noted after 3000 hours of wear; and continued losses, which amounted to approximately one ounce per square yard, were observed at the end of the third period (Table 18). Apparently the weight of such fabrics decreases with continuing wear.

Thickness. The trouser materials became thinner with increased amounts of wear. After eliminating the dry cleaning and storage factors, a slight increase in thickness was noted after the first wear period, followed, however, by losses throughout the second and third periods which were approximately the same for all three fabrics. Forty-five hundred hours of wear alone resulted in a little more than three thousandths of an inch decrease in thickness.

Yarn count. Yarn count data had given evidence of increases after each period of storage, dry cleaning, and wear; and, according to the mean squares for periods, all of these increases are highly significant in the fillingwise direction. A comparison of mean squares indicated that dry cleaning caused the greatest gain in yarn count in the warpwise direction, whereas wear is shown here to have caused the largest gain fillingwise, these gains approximating two yarns per inch in most cases. The net results for wear as shown in Table 18 seem to verify these observations.

Breaking strength. Comparatively little variation in breaking strength has been shown to result from three periods of storage, although the mean squares for these changes were significant at the five percent level. Dry cleaning produced

Table 18. The Effect of Wear at the End of Each Period as Shown by Differences Between Worn and Stored and Dry Cleaned Materials[1]

Property measured	Unit of measure	Periods	12-ounce serge	14-ounce serge	16-ounce serge
Weight per sq. yd.	ounces	I	+0.25	+0.14	+0.12
		II	−0.63	−0.80	−0.53
		III	−0.99	−0.92	−1.26
Thickness	1/1000 in.	I	+0.83	+0.48	+0.30
		II	−1.35	−1.30	−1.25
		III	−3.37	−3.28	−3.40
Yarn count	number	I	+1.1	+1.3	+0.9
warps	per inch	II	+1.0	+0.9	+0.5
		III	+0.5	−0.8	−0.9
fillings		I	+2.5	+2.2	+2.0
		II	+2.0	+2.5	+1.9
		III	+1.7	+1.8	+1.3
Breaking strength	pounds	I	−1.98	−0.86	−1.68
warpwise		II	−9.14	−7.20	−4.40
		III	−15.36	−16.97	−23.33
fillingwise		I	+0.94	+0.30	−0.32
		II	−10.59	−9.64	−5.38
		III	−17.39	−22.89	−26.22
Bursting strength	pounds	I	−4.22	+0.72	−4.32
		II	−20.42	−18.55	−12.18
		III	−33.30	−28.80	−46.15
Elongation—breaking test	percent	I	−2.11	+0.25	−0.37
warpwise		II	−7.74	−5.00	−7.38
		III	−10.59	−9.40	−10.44
fillingwise		I	−1.26	−1.86	−1.67
		II	−6.74	−9.07	−7.96
		III	−12.59	−14.07	−14.22
Elongation—bursting test	percent	I	0.00	+0.47	+0.47
		II	−4.39	−3.81	−4.01
		III	−8.38	−2.29	−5.71

[1]The plus sign indicates a gain and the minus sign a loss when values for the stored and dry cleaned materials are used as a basis for comparison.

slightly larger changes in breaking strength and these too are significant only at the five percent level.

Wear plus dry cleaning and storage resulted in highly significant losses in strength. The net losses attributable to wear vary from 0.86 to 23.33 pounds warpwise, and 0.32 to 26.22 pounds fillingwise. These losses increased markedly during each of the last two wear periods in both directions of the cloth, and the loss in the case of the 16-ounce fabric during the last wear period was outstanding. In the early stages of wear the strength of wool serge is not greatly influenced, but thereafter strength decreases as wear increases.

Bursting strength. Storage and dry cleaning seem to have had little effect upon the bursting strength of these fabrics. However, wear alone caused losses which became increasingly larger as wear continued (Table 18). This effect is most marked in the 16-ounce fabric after 4500 hours of wear, as was also the case for breaking strength.

Fabric elongation. Elongation due to breaking forces gave evidence that an increased amount of wear alone resulted in a decreased capacity for elongation. Storage had shown little effect in this respect, while dry cleaning had shown a definite increase. However, wear alone caused decreases which were large enough to overcome the increases due to dry cleaning, and which amounted to maximum losses of 10.59 percent elongation warpwise, and 14.22 fillingwise. Increasing amounts of wear alone decrease the extensibility of this type of material.

Elongation resulting from bursting forces showed only a small amount of variation after each period of service for the trousers, yet the mean squares for periods were highly significant in each case. Eliminating the effects of storage and dry cleaning, it is seen in Table 18 that no marked change occurs during the first period. During the second and third periods, however, capacity for elongation decreases with increased wear, although not to the same degree as was noted for elongation due to breaking forces.

INFLUENCE OF WEAR ALONE ON YARN PROPERTIES. *Yarn strength.* Values for yarns from the worn garments have indicated considerable loss in yarn strength during wear periods. Other data have shown also that dry cleaning and storage were responsible for but little of this variation, thus indicating that wear was the major factor in this respect. Net results due to wear alone are given in Table 19, and these indicate losses in yarn strength in all but one case. These losses show a progressive trend for the 16-ounce fabric warpwise, and all three fabrics fillingwise as wear increases. Since breaking strength showed increasing losses due to wear, it is to be expected that yarn strength should be affected similarly.

Table 19. The Effect of Wear on Yarns at the End of Each Period as Shown by Differences Between Measurements on Yarns from the Worn and the Dry Cleaned and Stored Materials.[1]

Property measured	Unit of measure	Periods	12-ounce serge	14-ounce serge	16-ounce serge
Yarn strength	grams	I	—25.3	+5.2	—23.0
warpwise		II	—61.6	—93.6	—41.3
		III	—54.9	—77.9	—126.7
fillingwise		I	—27.9	—17.7	—29.4
		II	—84.5	—114.6	—53.8
		III	—112.1	—156.5	—176.5
Yarn elongation	percent	I	—1.63	+0.45	—0.48
warpwise		II	—3.00	—4.20	—0.93
		III	—3.13	—3.38	—5.04
fillingwise		I	—1.47	—0.76	—0.01
		II	—3.23	—4.39	—1.65
		III	—4.99	—5.73	—4.15

[1]The plus sign indicates a gain and the minus sign a loss when yarns from the stored and dry cleaned materials are used as a basis for comparison.

PREDICTION OF SERVICEABILITY

Yarn elongation. Changes in yarn elongation resulting from wear alone show decreases in extensibility in every case but one. The same trends are apparent here as were noted for yarn strength.

The service which any consumer might expect from a piece of cloth is difficult to foretell, although such a prediction would be of inestimable value to the purchaser.

Based on residual values for thickness, breaking strength in both directions of the cloth, and bursting strength, after 4500 hours of wear, this 12-ounce serge would appear to be inferior to the 14- and 16-ounce materials. At the same time the latter two were notably similar at this stage of wear with respect to these properties.

If the decreases in the measured physical characteristics were expressed as percentages of values for the new material, another aspect of the picture is shown. From this angle, the percentage losses in thickness and in warpwise breaking strength and elongation are nearly equal for the 12- and 14-ounce fabrics, while the corresponding losses for the 16-ounce material are greater. In addition, it has been noted previously that fewer visual evidences of wear were recorded for the 14- than for the 12- and 16-ounce fabrics. Together those relationships point to the probability that, for prolonged wear, the 14-ounce serge would prove as satisfactory as the 16-ounce fabric, so far as these properties have portrayed wear, and in some cases it might be less expensive.

The considerable amounts of service represented by these three wear periods have been shown to have caused marked decreases in many of the properties measured. However, it would have been impossible to have predicted, from the original values for the new fabrics alone, exactly those changes which did occur, the extent of such changes in fabric properties, or the relationships which were found among the residual values for these three materials after an appreciable amount of wear.

These measurements have been useful in showing the effects of wear, but no relationships have been established by means of which the properties measured could be shown to have supplied a basis, before wear, for the prediction of the serviceability of either the 14- or the 16-ounce fabric, in this group. The 12-ounce serge consistently yielded low values for weight, thickness, strength, and elongation, both before and after wear.

Summary

Three weights of new all wool serge were made into trousers which were worn by men students at South Dakota State College. Three trousers of each material were worn for 1500 hours, three for 3000 hours, and three for 4500 hours, and all were dry cleaned after every 300 hours of wear.

Physical measurements were made at the University of Minnesota laboratory on the worn garments and on lengths of new fabric, representing (1) samples which were stored for a period of time equivalent to the time the trousers were used, and (2) samples which were stored and dry cleaned the same number of times as each group of trousers, the time element again being the same. With this plan it was possible to attempt to ascribe the variations which were observed to wear, to dry cleaning, to storage, or to a combination of any or all of these factors.

The measurements made on the fabrics from the trousers were weight per square yard, thickness, yarn count, strip breaking strength and elongation, bursting strength and elongation, and yarn strength and elongation. These same measurements were repeated on the new, on the stored, and on the stored and dry cleaned fabrics with the addition of tearing strength, shrinkage, yarn number and yarn twist.

For the new materials it might be expected that strength, elongation and other physical properties would show progressive changes since weight and thickness increased in equal amounts when comparing the three serges. This has been shown not to be true for these fabrics, since in many instances the largest differences occurred between the 12- and 14-ounce fabrics, and in several cases the values for the 14- and 16-ounce materials were nearly alike. On this basis it would be difficult to predict for the 16-ounce serge an increase in service over that for the 14-ounce fabric which would be equal to the difference between the latter and the 12-ounce material.

The effect of light, which simulates sunlight, upon these fabrics was evidenced in large losses of original strength after continued exposure. Of the three fabrics, the 16-ounce serge seemed to stand up a little better than either the 12- or 14-ounce materials since it retained a slightly larger proportion of its original strength after such exposure. Unnecessary exposure to sunlight should be avoided in order to obtain maximum service.

Aging or storage did not give evidence of being a highly important factor in the life of these wool garments. A few changes were observed in physical properties after storage but these were comparatively small.

Dry cleaning did not produce marked changes in the fabrics, but some minor variations were noted. All of the fabric properties showed small increases with the exception of tearing strength and elongation due to bursting forces, for which small losses were observed. It is considered probable that these increases could have resulted from some possible shrinkage which might have occurred during the process of dry cleaning.

Wear alone caused these materials to lose weight, thickness, strength, and extensibility, and is thought to be chiefly responsible for the deterioration of the fabric in these garments. The first wear period showed small changes in many instances, but continued wear resulted in losses which were of considerable magni-

tude and which became increasingly larger as wear progressed. Based on outstanding losses in strength and weight due to wear alone, it might be concluded that the 16-ounce serge apparently would not give the ultimate service which might be expected of the heaviest of the three fabrics.

Visual observations of wear on the trousers indicated that most of the effects of service became apparent after about 1500 hours and before 3000 hours of wear. The character of evident wear and location of worn areas were obvious—holes and fraying at the turn of the cuff, frayed and worn pocket edges, holes in the seat area, threadbare and worn buttonholes. Considerable mending was necessary by the end of 4500 hours, but many of the trousers could have been worn longer.

The effect of service, which includes wear, aging and dry cleaning, and the conditions under which the garments are used, in general was evidenced by changes in properties of the three serges used for trousers. At some time between 1500 and 4500 hours of wear, all three fabrics became lighter in weight, thinner, weaker and less extensible. These changes paralleled visual observations of wear. At the same time the small increases in number of yarns per inch which were observed are thought to have resulted from some slight shrinkage which may be associated with cleaning or use.

In choosing one of these fabrics to be used for men's wear, the lightest of the three serges would prove least serviceable. The 14-ounce serge appears to represent the wisest choice as shown by losses in fabric properties and recorded evidences of wear. Of the three, the 16-ounce fabric deteriorated most rapidly after 3000 hours of wear.

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Appendix

Appendix Table I. Mean Values of Physical Properties for Worn Fabrics after Three Periods of Wear

Property measured	Unit of measure	Wear period	Area of trousers	12-oz. serge Warp	12-oz. serge Filling	14-oz. serge Warp	14-oz. serge Filling	16-oz. serge Warp	16-oz. serge Filling
Weight per sq.yd.	ounces	I		8.21		9.25		10.50	
		II		7.48		8.40		9.94	
		III		7.05		8.28		9.18	
Thickness	1/1000 in.	I		24.63		26.63		28.50	
		II		23.10		25.20		27.25	
		III		21.58		24.37		25.50	
Yarn count	number per inch	I		66.4	58.8	57.1	55.7	57.3	55.5
		II		67.1	59.4	57.6	57.1	57.4	56.2
		III		67.4	59.0	57.1	56.3	57.4	56.2
Breaking strength	pounds	I	Top	45.77	43.05	51.50	55.67	61.47	58.60
			Middle	45.72	42.58	53.18	55.92	61.45	59.28
			Bottom	47.48	45.45	55.48	59.42	64.20	62.35
			Mean	46.32	43.69	53.39	57.00	62.37	60.08
		II	Top	38.62	33.45	47.53	49.57	61.25	55.20
			Middle	37.73	32.20	45.40	43.20	59.97	52.87
			Bottom	41.42	38.77	51.22	53.52	63.43	60.90
			Mean	39.26	34.81	48.05	48.76	61.55	56.32
		III	Top	32.90	27.50	39.45	38.57	44.65	36.95
			Middle	31.88	23.98	38.12	29.27	40.15	31.62
			Bottom	37.78	34.93	42.83	40.18	45.02	43.88
			Mean	34.19	28.81	40.13	36.01	43.27	37.48
Bursting strength	pounds	I		101.53		126.07		140.38	
		II		87.48		107.75		126.27	
		III		74.90		98.40		99.65	
Elongation breaking test	percent	I	Top	25.00	21.44	26.45	23.89	27.78	25.11
			Middle	25.89	21.00	30.00	25.00	29.56	25.78
			Bottom	28.78	24.78	32.33	27.56	34.55	30.11
			Mean	26.56	22.41	29.59	25.48	30.63	27.00
		II	Top	26.23	19.89	27.78	20.89	28.89	22.67
			Middle	26.22	17.67	25.00	17.00	29.44	21.56
			Bottom	29.33	24.22	30.22	25.89	31.55	27.89
			Mean	27.26	20.59	27.67	21.26	29.96	24.04
		III	Top	20.33	15.11	23.89	19.22	24.00	18.22
			Middle	21.33	13.56	23.33	14.67	21.89	16.00
			Bottom	25.56	20.56	27.56	19.89	24.78	23.11
			Mean	22.41	16.41	24.93	17.93	23.56	19.11
Elongation bursting test	percent	I		14.29		17.62		16.19	
		II		17.33		19.62		17.71	
		III		15.05		18.29		15.43	
Yarn strength	grams	I		247.7	199.3	362.6	306.9	419.4	319.2
		II		187.3	140.0	306.6	242.9	413.1	314.2
		III		221.5	156.7	312.5	213.5	333.1	209.7
Yarn elongation	percent	I		11.41	7.34	14.07	9.44	12.51	8.53
		II		10.37	6.83	11.78	8.02	12.77	8.48
		III		10.15	5.95	11.01	5.94	8.85	6.02

Appendix Table II. Significance of Differences, According to "t" Tests, Between Physical Measurements for Three Weights of New Wool Serge[1]

Property measured	Unit of measure	Direction of test	Comparing 12- and 14-ounce serge	Comparing 14- and 16-ounce serge
FABRICS				
Thickness	1/1000 in.		+3.20†	+2.85†
Breaking strength	pounds	warpwise	+8.50†	+8.05†
		fillingwise	+11.90†	+4.55*
Bursting strength	pounds		+24.10†	+10.20†
Tearing strength	pounds	warpwise	+2.60†	+0.10
		fillingwise	+2.05†	+0.30
Elongation-breaking test	percent	warpwise	+3.33	+1.66
		fillingwise	+8.00†	—0.66
bursting test	percent		+10.00†	—5.72
YARNS				
Number	worsted count	warpwise	—4.18†	—2.04†
		fillingwise	—2.93†	—0.58
Twists per inch	number	warp	—1.48†	—1.02†
		filling	—1.02†	—0.61†
Strength	grams	warp	+101.2†	+73.6†
		filling	+76.0†	+27.6*
Elongation	percent	warp	+1.70*	—0.36
		filling	+0.86	—1.28
FIBERS				
Length	inches	warp	+0.33	—0.35
		filling	—0.41	+0.06
Diameter	microns	warp	+2.59†	—0.01
		filling	+2.26†	+1.96†

[1]The plus sign indicates a gain and the minus sign a loss when comparisons are made using the lighter weight fabrics as a basis for comparison.

*Significant ("t" value exceeds the 5-percent level of significance).

†Highly significant ("t" value exceeds the 1-percent level of significance).

Appendix Table III. Values for Fabric and Yarn Properties of the Stored Fabrics after a Specified Number of Dry Cleanings

Property measured	Unit of measure	No. of cleanings	12-oz. serge Warp	12-oz. serge Filling	14-oz. serge Warp	14-oz. serge Filling	16-oz. serge Warp	16-oz. serge Filling
Weight per sq. yd.	ounces	5	7.96		9.11		10.38	
		10	8.11		9.20		10.47	
		15	8.04		9.20		10.44	
Thickness	1/1000 in.	5	23.80		26.15		28.20	
		10	24.45		26.50		28.50	
		15	24.95		27.65		28.90	
Yarn count	number per inch	5	65.30	56.30	55.80	53.50	56.40	53.50
		10	66.10	57.40	56.70	54.60	56.90	54.30
		15	66.90	57.30	57.90	54.50	58.30	54.90
Breaking strength	pounds	5	48.30	42.75	54.25	56.70	64.05	60.40
		10	48.40	45.40	55.25	58.40	65.95	61.70
		15	49.55	46.20	57.10	58.90	66.60	63.70
Bursting strength	pounds	5	105.75		125.35		144.70	
		10	107.90		126.30		138.45	
		15	108.20		127.20		145.80	
Tearing strength	pounds	5	4.95	5.05	6.95	7.50	7.45	7.20
		10	4.60	4.90	6.05	6.95	6.60	6.70
		15	4.50	4.65	5.45	6.50	6.45	6.70
Elongation—breaking test	percent	5	28.67	23.67	29.34	27.34	31.00	28.67
		10	35.00	27.33	32.67	30.33	37.34	32.00
		15	33.00	29.00	34.33	32.00	34.00	33.33
Elongation—bursting test	percent	5	14.29		17.15		15.72	
		10	21.72		23.43		21.72	
		15	23.43		20.57		21.14	
Shrinkage from sponging	percent	5	4.89	2.11	4.78	1.83	3.94	1.50
		10	3.94	1.50	3.94	1.74	3.01	1.16
		15	3.82	1.50	3.12	1.74	3.36	1.74
Yarn strength[1]	grams	5	273.0	227.2	357.4	324.6	442.4	348.6
		10	248.9	224.5	400.2	357.5	454.4	368.0
		15	276.4	268.8	390.4	370.0	459.8	386.2
Yarn elongation[1]	percent	5	13.04	8.81	13.62	8.68	12.99	8.54
		10	13.37	10.06	15.98	12.41	13.70	10.13
		15	13.28	10.94	14.39	11.67	13.89	10.17

[1]Average of 50 determinations.

Appendix Table IV. Values for Fabric and Yarn Properties after Three Periods of Storage

Property measured	Unit of measure	Storage period	12-oz. serge Warp	12-oz. serge Filling	14-oz. serge Warp	14-oz. serge Filling	16-oz. serge Warp	16-oz. serge Filling
Weight per sq. yd.	ounces	I	7.72		9.02		10.13	
		II	7.75		9.12		10.01	
		III	7.79		8.94		10.11	
Thickness	1/1000 in.	I	19.25		23.80		24.55	
		II	19.65		23.65		24.20	
		III	22.00		22.85		25.15	
Yarn count	number per in.	I	64.0	54.7	56.3	52.6	56.3	52.6
		II	65.2	55.0	56.0	53.4	56.4	53.4
		III	65.0	55.1	56.8	53.4	56.6	53.3
Breaking strength	pounds	I	47.80	43.55	55.45	56.70	64.80	59.00
		II	49.50	46.50	57.70	59.00	67.60	64.10
		III	48.95	44.75	56.10	58.00	66.15	59.90
Bursting strength	pounds	I	102.30		124.90		140.15	
		II	102.75		129.20		137.45	
		III	106.65		121.70		143.80	
Tearing strength	pounds	I	5.45	5.65	7.75	8.20	8.10	7.85
		II	5.25	5.50	7.40	7.55	7.30	7.40
		III	5.50	6.10	7.75	8.15	8.00	7.90
Elongation—breaking test	percent	I	25.00	22.33	28.33	27.00	29.67	27.00
		II	26.33	24.33	27.67	27.34	29.00	29.33
		III	25.00	24.33	30.00	29.67	30.00	31.67
Elongation—bursting test	percent	I	22.86		18.57		17.15	
		II	22.29		24.57		22.86	
		III	22.86		22.29		24.00	
Shrinkage from sponging	percent	I	6.50	3.22	5.78	2.22	5.89	2.00
		II	6.71	2.32	6.14	1.97	6.71	1.97
		III	6.36	2.43	5.90	2.08	5.44	1.74
Yarn strength[1]	grams	I	259.4	224.8	383.2	343.2	429.0	351.2
		II	242.9	209.1	358.7	315.3	454.6	360.7
		III	270.0	246.1	389.3	352.4	449.0	353.6
Yarn elongation[1]	percent	I	10.92	9.11	16.01	12.20	13.69	10.46
		II	13.88	9.83	16.16	13.45	14.68	10.56
		III	12.84	9.44	14.16	10.98	12.83	9.67

[1]Average of 50 determinations.